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APPLICATION AND EXPANSION OF THE MODULAR
COMMAND & CONTROL EVALUATION STRUCTURE
(MCES)
AS A FRAMEWORK FOR ACQUISITION
MANAGEMENT

by

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Application and Expansion of the Modular Command & Control Evaluation Structure (MCES) as a Framework for Acquisition Management

by

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requirements for the degree of

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ABSTRACT

This thesis provides a description of a collection of "tools" which may be used by acquisition program managers. The Modular Command and Control Evaluation Structure (MCES) provides the framework for management of the process. The Marine Corps Technical Interface Concepts (TIC) and interoperability database (IDB) are discussed as standards for filling four of the seven MCES modules. Finally, generic measures of communications system performance are described and used in conjunction with System Effectiveness Analysis (SEA) to define the analytical process of measuring effectiveness.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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I. INTRODUCTION

A. BACKGROUND

Acquisition of major weapons systems has become a progressively more complicated process. This is due, in part, to the complexity of modern warfare. Integrated (interoperable) command and control (C^2) systems are required to effectively harness and employ the destructive nature of military forces. Integration demands measures to overcome technical intricacies and efforts to master the political and cultural pressures highlighted in the following quote [Ref. 1: p. ii].

> GETTING INTERSERVICE AGREEMENT IS THE MOST DIFFICULT PHASE: Service differences in doctrines, operations, logistics, and procedures tend to diversify system designs. When joint acquisitions are ordered by the Secretary of Defense or the Congress, the biggest hurdle is getting the services to agree on joint requirements. Each service believes that its concept of a new aircraft, missile, or vehicle will be best for the mission and will oppose compromise of its design or performance goals. Agreement is still more elusive when one or another system is already well into development with a "hardened" design, decisions firmed, costs sunk, and a dedicated constituency in place. This is when many program mergers are ordered.

The Department of Defense has outlined procedures directed at resolving integration (interoperability) issues. At the heart of this enterprise is a requirement to outline a joint Command, Control and Communications (C^3) architecture and to build a joint interoperability database [Ref. 2: p. 4-5]. The multifarious nature of this endeavor makes it necessary to collect tools to describe, in structured terms, the process of command and the communications necessary to control diverse elements.

B. SCOPE

This thesis will focus on four tools that can be used by acquisition managers to consolidate and refine the measures and specifications necessary to affect a systematic approach to procurement. Specifically, these devices can assist supervisors in refining mission needs and stipulating the requirements necessary to meet these demands. The Modular Command and Control Evaluation Structure (MCES) will provide the framework for evaluating C^2 architectures. Generic system attributes need to be defined and assigned numeric values, where possible and practical, to be analyzed. This thesis will define, in the author's words, essential communications considerations

used by Marine Corps communications managers. Marine Corps Technical Interface Concepts (TIC) are applied to describe the boundaries and process definitions, integrate these descriptions, and then provide data for specified measures. Finally, System Effectiveness Analysis (SEA) outlines a quantitative approach to aggregate and evaluate recommended measures.

C. THESIS OUTLINE

This thesis is organized into eight chapters. Chapter II describes the framework of MCES, in acquisition related terms. Chapter III defines communications attributes. While not an all-encompassing list, it provides generic considerations to be used to specify Measures of Performance or Effectiveness. Chapter IV outlines the Marine Corps Technical Interface Concepts followed by an explanation of System Effectiveness Analysis (Chapter V). Chapter VI then applies the previously described tools to a C^3 system. Chapter VII summarizes the results and recommends areas for further research. Appendix A provides a dictionary of acronyms and terms used to describe this process. The sources for these definitions include JCS Publication 1, "DoD Dictionary of Military and Associated Terms," January 1986, and the references cited throughout the text. This thesis assumes a basic knowledge of communications engineering principles and of the acquisition process. Appendix B provides an overview of the acquisitions process. Inasmuch as regulations are constantly changing, Appendix B is somewhat dated; however, the principles and structure remain essentially unchanged.

II. MODULAR COMMAND AND CONTROL EVALUATION STRUCTURE (MCES) METHODOLOGY

A. INTRODUCTION

The Modular Command and Control Evaluation Structure (MCES) is a framework for systems planners and evaluators to assess C^2 architectures. By extension, it is a useful basis for analyzing the communications processes necessary to support command and facilitate control. Its functional applications may extend beyond the bounds of C^3 studies. This thesis will concentrate on defining its utility as an acquisitions guide to evaluate, inter alia, communications interoperability.

B. BACKGROUND

The development of MCES was initially triggered by a challenge to Air Force planners to determine the force effectiveness of C^2 systems. This implied a search for a means of analyzing these systems throughout their life-cycle. Expert knowledge of the analytic community was focused through a conference chaired by Dr. Ricki Sweet and LtCol Thomas Fagan III, USAF. Five working groups were formed to address: Definitions, Conceptual Models, the Identification of Measures of Effectiveness (MOEs), Evaluation Techniques and Approaches and an overall appraisal of the current status and future course of MOE analysis.

Based on an expressed interest and need for further attention to C^2 systems' contribution to force effectiveness, an effectiveness "strawman" was developed by Drs. Mort Metersky, Michael G. Sovereign, and Ricki Sweet to provide a framework for subsequent deliberations at the MORS (Military Operations Research Society) sponsored workshop. An integrated document describing MCES was published in June 1986 [Ref. 3: pp. 19-21]. MCES has been tested and refined through service community input [Ref. 4] and through the voluntary contribution of government, military and civilian agencies, and companies [Ref. 3: p. 24].

This chapter provides an explanation of MCES presented, where appropriate, with reference to DoD acquisition requirements. It is a restatement, in the author's words, of the methodology described by Dr. Sweet [Ref. 3: pp. 9-18].

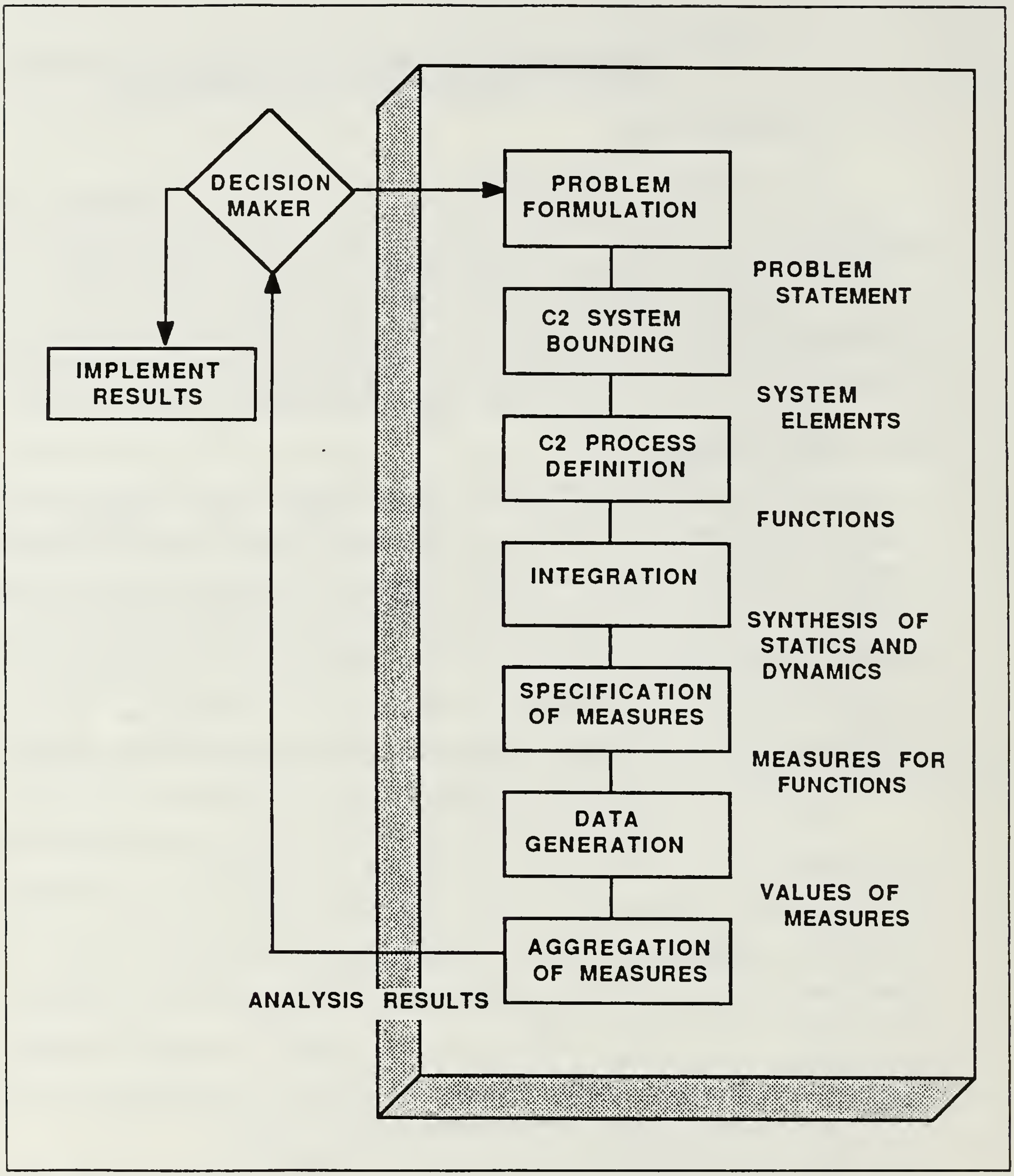

Figure 2.1 The Modular Command and Control Evaluation Structure.

C. METHODOLOGY

The MCES (Figure 2.1) consists of two components: (1) managerial and (2) analytical systems. The former guides the user through specification while the latter

outlines analysis processes (both objective and subjective). The MCES is intended to guide problem specification and analysis in order to provide a manager with concise conclusions thereby enhancing decision making. This direction is accomplished through use of seven modules using pragmatic, established techniques.

1. Module 1: Problem Formulation

Module 1 describes the decision maker's objectives. These objectives should fill a mission need and demonstrate a level of performance and reliability that justify the allocation of the Nation's limited resources for the system's ownership and/or acquisition [Ref. 5: p. 4]. Implementation of this module results in a more precise statement of the problem to be addressed. Problem formulation should consider elements of not only mission assignment but also the intelligence or threat assessment and scenario(s) underlying the analysis.

2. Module 2: C^2 System Bounding

The problem statement developed in Module 1 is then used to bound the C^2 system of interest. This module has been perhaps one of the most overlooked elements in preparation of acquisition strategies and Justification for Major System New Starts (JMSNS). Bounding the project allows managers and engineers to focus their efforts rather than attempt description of a panacea for all existing deficiencies. Module 2 specifies the first two of the three dimensions which define a C^2 system, namely:

- physical entities (equipment, software, people and facilities);
- structure (organization, concepts of operation and information flow patterns); and,
- process (the functionality or "what the system is doing").

Bounding in this module occurs when the project team defines who or what entities have a requirement to interact (process - the final C^2 dimension developed further in the next module) in what manner or along what lines (structure).

3. Module 3: C^2 Process Definition

Understanding the system bounds allows a focused description of Command and Control processes (Module 3). Other generic models such as Boyd's O-O-D-A and Lawson's control loop are applied to force attention on:

- the environmental "initiator" of the C^2 process;
- the internal processes that characterize what the system is doing (ex. sense, assess, generate, select, plan, and direct) (see Figure 2.2); and/or,
- the inputs and desired outputs from the internal process.

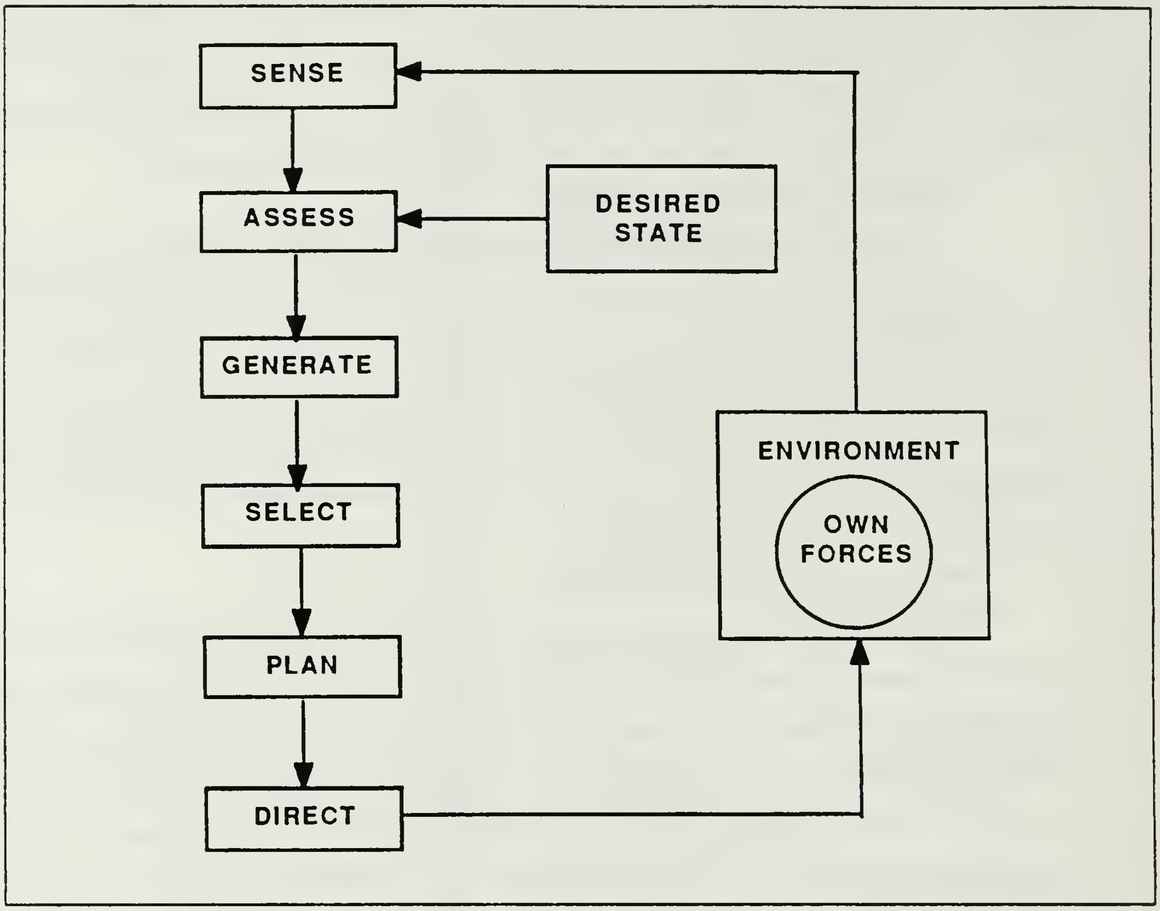

Figure 2.2 Generic Command and Control Process.

4. **Module 4: Integration of System Elements and Functions**

The fourth module verbally or graphically depicts the three dimensional system. It maps entities with their required processes, forming the structure necessary to answer the mission objective of Module 1. Techniques such as Data Flow Diagrams (DFDs) are frequently used to show the information flow through the model. Hierarchical relationships are drawn as data progresses through the system to a decision maker or into master databases for further or future processing.

5. **Module 5: Specification of Measures (Criteria)**

The definitive processes of the preceding modules lead logically to the specification of measures necessary to address the problem of interest. These measures are classified as to their level of measurement.

a. Measures of Performance (MOPs)

Measures of Performance are specified inside the boundary of the C^2 system [Ref. 4: p. 17], that is, they measure performance of the system processes. A set of generic Communications MOPs will be presented in Chapter III. An example of a communications performance measure would be a specific bit error rate (BER) requirement for a data transmission system.

b. Measures of Effectiveness (MOEs)

Measures of Effectiveness (MOEs) are specified outside the boundary of the communications system [Ref. 4: p. 17]. MOEs are C^2 process measures placed on the system being evaluated in the context of the system's effect on the larger (Force) process. They describe a force action or lack thereof impacted or directed by the system. As an example, in order to ENGAGE an enemy (Force level) you first have to FIND or LOCATE (system level) him.

c. Measures of Force Effectiveness (MOFEs)

Measures of Force Effectiveness (MOFEs), then, describe the force effect on its environment. These combine all of the system's performance and effectiveness measures and could describe such things as battle outcome or target destruction. Figure 2.3 portrays the aforementioned relationships.

The specified measures are subjected to further scrutiny by comparing them to a set of criteria (Table 1) reducing the number to a more manageable set. The final list is taken to be critical or the minimum necessary to measure the problem at hand.

6. **Module 6: Data Generation**

Module 6 addresses the requirement to generate data relative to the Measures specified in Module 5. Data can be generated through any number of means (i.e., exercises, experiments, simulations, or subjective judgement). In the acquisition process, values are generated for specified measures relative to the force and environment (MOE MOFEs) and then to system entities (MOPs). This would imply a top-down design approach. It also implies an iterative process wherein specification dependencies are highlighted, analyzed and resolved. Chapters IV and V will describe a means of acquiring data to describe the generic communications MOPs outlined in Chapter III.

7. **Module 7: Aggregation of Measures**

The final module addresses aggregation or analysis of the previously defined system. As support for a JMSNS, analysis may determine the essential features of a

new system's effect on the force compared with programs already in existence (DoD Milestone 0). Following a decision to acquire (DoD Milestone 1), investigation is conducted into alternative means in order to refine requests for proposals (RFPs) and generate a specific statement of work (SOW). Finally, the system measures are compared with proposals and products through the full scale development phase and used to determine contractor qualification for contract.

Existing systems are evaluated as changes to mission statements and objectives are directed to demonstrate or validate their utility in the force as a whole.

D. DECISION MAKER

The products provided by the MCES modules are presented to a decision maker. Three general courses of action are then available. The results may be implemented based on the analysis. Alternatively, a need for further study, refining any or all of the Modules, may be directed. Finally, a decisionmaker may terminate the process. MCES does not define a specific decision process. This is left to the manager to describe. The process may be entirely subjective based on the evaluator's personal assessment of the data generated. It may be very objective, based solely on numbers generated combined with weighted measures. Or it could encompass any combination of these processes. As a generic tool, MCES specifies only the logical framework or process of the evaluation. It remains a function of leadership to define the decision process.

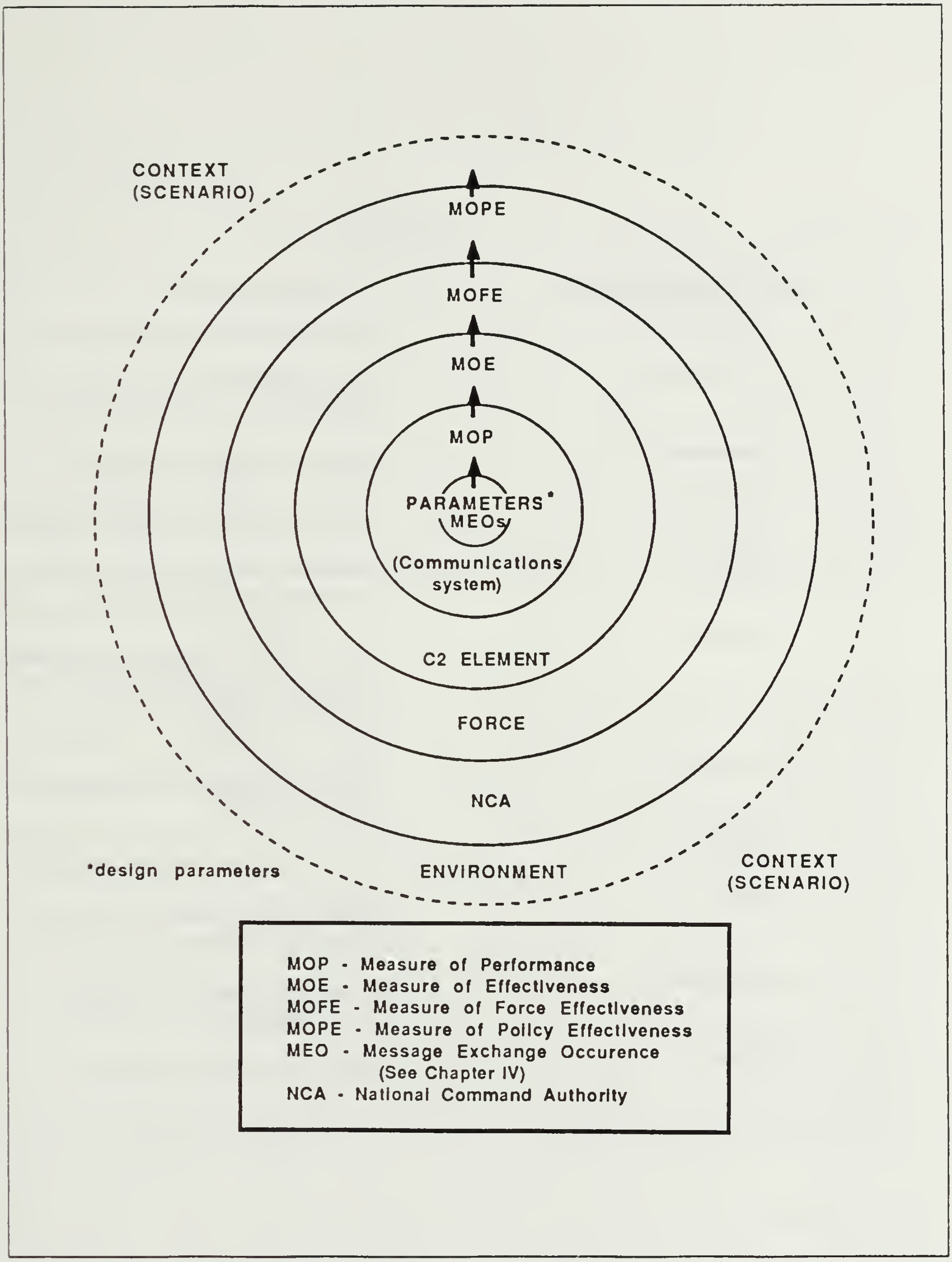

Figure 2.3 Measures Specification - The "Onion Skin".

TABLE 1

CRITERIA

CHARACTERISTICS	DEFINITIONS
Mission Oriented	Relates to force/system mission
Discriminatory	Identifies real difference between alternatives
Measurable	Can be computed or estimated
Quantitative	Can be assigned numbers or ranked
Realistic	Relates realistically to the C2 system and associated uncertainties
Objective	Can be defined or derived, independent of subjective opinion. (It is recognized that some measures cannot be objectively defined).
Appropriate	Relates to acceptable standards and analysis objectives
Sensitive	Reflects changes in system variables
Inclusive	Reflects those standards required by the analysis objectives
Independent	Is mutually exclusive with respect to other measures
Simple	Is easily understood by the user

III. MEASURES

A. INTRODUCTION

The MCES, described in Chapter II, directed specification of measures as the requirement for Module 5 of the Structure. This chapter will describe the efforts of JTC^{3}A in their research on specifying measures [Ref. 6] and then outline generic communication system measures, recommended by this author, to be considered as a guide in acquisition planning. The Technical Report referenced in the introduction and its accompanying appendix [Ref. 7] present the preliminary JTC^{3}A results on assessment and evaluation techniques for joint tactical command, control and communications systems, networks, links and facilities. The JTC^{3}A work has attempted definition of MOE's for five major C^2 elements (see Table 2). In keeping with the thesis scope, the controlling factors outlined will refer to the *communications* element of the C^3 architecture.

B. BACKGROUND

Analysts define and use MOEs in the development of system and sub-system architectures. Commencing with work conducted by the Joint Tactical Communications Office (TRI-TAC) in the 1970-80 time period in which seventeen measures were published, to date about two hundred MOEs have been identified and defined by JTC^{3}A [Ref. 6: p. 4]. Some of these are hardware oriented and therefore technical in scope such as "ECCM/LPI", "Antenna Gain", and "Transmission Power." Others are non-technical requirements relating to such functions as "Monitoring", "Capability to Select Options, Employ Forces, and Execute Operations" and "Responsiveness to Warning and Threat Assessments." Certain measures address total system orientation such as "Maintainability", "Survivability", and "Mobility." JTC^{3}A emphasizes that "...these MOEs are structured for preliminary design comparison." In the MCES framework, they are also useful when applied and evaluated in an iterative fashion as tools to define the system or sub-system bounds. In other words specification of the measures themselves may help refine initial bounding when performance or effectiveness standards (MOPs/MOEs) fail to meet or answer problem objectives. This occurs as the decision maker is presented with architectural alternatives which address a stated mission need (determined in Module 1).

C. MOE ORGANIZATION AND FORMAT

The JTC^{3}A listing of MOEs is organized into five groups as shown in Table 2 These correspond to the five major C^2 elements mentioned in OJCS SM-7-82 [Ref. 6: p. 5]. They are divided further into sub-elements, also illustrated in Table 2. Communications is visualized as the bonding agent of C^2 systems and is categorized in terms of "transmission" and "connectivity/distribution." Keeping with the scope of this work, this author will describe the *Communications* category and specific generic measures to be considered when describing or defining a system. This is contrary to the global JTC^{3}A approach wherein measures are specified by communications media type.

Reference 7 uses the format presented in Table 3 to present specific measures. Inasmuch as this represents a goal which JTC^{3}A has yet to realize, the title and definition of each measure will be used in this thesis. Comments regarding evaluation will be presented in a discussion section. Sources and data requirements will be omitted for the generic measures. The "MOP or MOD Title" line refers to the Measures of Performance (MOP) previously discussed and Measures of Design (MOD) representing field operational characteristics (ex., "Transportability" and "Maintainability"). The reference admits no great significance in the distinction [Ref. 6: p. 6]. In order to prevent confusion and follow the MCES outline, only "MOPs" will be listed in the title lines for this work.

D. GENERIC MEASURES

1. Introduction

This section presents generic measures of performance to be applied to communications systems analysis in the MCES framework. The measures listed are in no particular order of importance. While perhaps lacking in depth of description and breadth of attribute (measure) coverage, it should provide the reader a skeleton on which to build a more comprehensive listing. It is understood that many of these measures are interrelated. Parameters or characteristics of one may impact or affect another. Some of these relations are highlighted. Others may have been omitted. It remains a requirement for the analysis team using these measures to describe interdependencies as complementary or disparate and develop the decision tools to compromise or obviate differences. JTC^{3}A also emphasized that their measures are proposed for *communications* systems *only*. This also applies herein. The measures

TABLE 2

ORGANIZATION OF JOINT TACTICAL C3 MOE CATEGORIES

1. Command Facilities
    A. Main Command Centers
    B. Alternate Command Centers

2. Communications
    A. Tactical HF Systems
    B. Line of Sight Systems
    C. Tropo
    D. Switching
    E. Wire/cable/fiber optics
    F. Satellite
    G. Combined System Networks

3. Warning (Surveillance)

    A. Ground
    B. Surface
    C. Sub-surface
    D. Space Based
    E. Tethered Balloons

4. Command and Control Procedures

    A. Procedures
    B. Reports
    C. Frame Formats
    D. Modularity Techniques

5. Command and Control Data Collection and Processing

    A. Netted Systems
    B. Centralized Data Bases
    C. Point-to-point Systems

discussed stem from system *attributes* defined for Marine communications managers. It is felt that *attributes* of an efficient effective communications system should relate to *measures* used in evaluating proposed and existing systems.

TABLE 3

FORMAT FOR EACH MOE

MOP or MOD TITLE:

DEFINITION: or description of what the title measures

METHODOLOGY: either qualitative or quantitative for preparing the measure, including important parameters, factors, models and considerations

SOURCES: that are useful for further research

DATA REQUIREMENTS: for using the algorithms and models

2. Reliability

a. Definition

Measures (the) probability that an item will perform its intended function for a specified interval under stated conditions [Ref. 7: p. A-14].

b. Discussion

Reliability is usually expressed in terms of Mean Time Between Failure (MTBF). Coupled with *maintainability*, it impacts *availability* of the communications system. MTBF is usually measured in hours. Military standards exist to describe component specifications and, by extension, can be used to describe system requirements.

Reliability may imply *redundance* which measures duplication of components. A high reliability requirement coupled with low MTBF will normally require redundancy which will usually impact system life cycle cost (both initial procurement and supportability).

Component reliability measures may depend on element placement in the C^2 system. Higher priority elements will normally require higher restoral ability, impacting the value assigned to reliability.

Link reliability expresses an assurance that communications will function accurately [Ref. 8: p. 2-4]. In this sense transmission efficiency, receiver sensitivity, and receiver selectivity are considered quantitative measures.

c. Conclusion

The following elements can be used in defining a reliability measure:

- Overall Reliability Requirement (Measured in percentages)
  - Component MTBF (in hours)
  - Redundancy (No. of backup components required)
  - Receive Sensitivity (ability to detect signals)
  - Receive Selectivity (ability to differentiate signals)
  - Transmission Efficiency (includes SNR/Error Detection Techniques)
  - Required Bit-Error-Rate (BER)
  - Mean Time to Repair (MTTR)

3. **Interoperability**

a. Definition

The condition achieved among communications electronics systems or items of communications electronics equipment when information or services can be exchanged directly and satisfactorily between them and/or their users. The degree of interoperability should be defined when referring to specific cases.

The ability of systems, units, or forces to provide services to and accept services from other systems, units or forces and to use the services so exchanged to enable them to operate effectively together. (JCS Pub 1)

b. Discussion

Communications interoperability, while seemingly simple to define, has been characteristically difficult to attain. Interoperability is a function of:

- Equipment compatibility;
- Interface operating procedures; and,
- Message formatting and design standards.

Interoperability may be measured with respect to any or all of these functions. Technical Interface Standards consist of specifications of the functional, electrical, and physical characteristics necessary to allow the exchange of information across an interface between different tactical C^3I systems or equipment [Ref. 2: p. 2-1]. Procedural standards consist of specifications for the manner of accomplishing the exchange of information across an interface. They define:

- The form or format in which information is to be exchanged;
- the prescribed information exchange language, syntax, and vocabulary to be used in the information exchange; and,

- interface operating procedures that govern the information exchange [Ref. 2: p. 2-1].

(1) *Compatibility.* Elements or parameters to be considered when ensuring communications compatibility include modulation, frequency range, range, signalling, cryptographic hardware and software, and interface connectivity. Of the aforementioned parameters, interface connectivity is, at times, the most difficult element of compatibility element to achieve. Intra and interservice Command and Control Elements (C^2E's) use a wide variety of computer and radio control equipments. In designing a system, existing terminal devices must be considered for numerous reasons, not the least of which is cost. DoD has a stated policy to minimize the number of buffering, translative, or similar devices to achieve interoperability [Ref. 9: p. 2]. A judicious use of modems, buffers and translaters must routinely be designed into communications architectures to ensure interoperability.

(2) *Message Formatting and Design.* Message formating and design features are specified in the JCS, JINTACCS (Joint Interoperability of Tactical Command and Control Systems) program as well as in Technical Interface Design Plans (TIDPs) (Addressed in Chapter IV). Elements are combined, in an approved sequence, to form a standard message. Once it is determined that input messages to a transmitting device match output messages in a receiver, *compatibility* is said to exist. Where discontinuities exist, measures are taken to resolve differences. For example, if operationally required formats do not exist in the JINTACCS system, then justification is drawn to include the message as a new standard. Once this justification is accepted, new message formats are derived. A process wherein this is accomplished is described in Chapter IV, Technical Interface Concepts.

(3) *Interface Operating Procedures.* Interface operating procedures, while ultimately linked to the format and design features already addressed, are developed as a result of Combined and Joint Service training and exercises. These require agreement on the part of all agencies as to, ultimately, the method(s) by which elements, commands, and forces are directed or controlled in a tactical environment. There are several stumbling blocks to acquisition planners as well as operational commanders. First, achieving a unified view is particularly difficult given unit and service parochialism. Next, qualifying or quantifying this requirement requires extensive operational tests and/or simulation. Finally, tradeoffs that are made during the acquisition process may impact reliability, speed, flexibility, economic factors, or even the entire project success.

c. Conclusion

The following elements can be used in quantifying an interoperability measure:

- Overall Communications Interoperability Requirement (Measured in Percentages)
  - Modulation - The extent to which both equipments are capable of operating using the same modulation scheme
  - Frequency Range - The extent to which equipments have the same (or nearly the same) frequency range and tuning capability to accommodate assigned frequencies (applicable for RF systems)
  - Range - distance or coverage of the system affected by transmit power, antenna gain, receive sensitivity, repeaters, propagation and terrain
  - Signalling - The nature of such types as analog or digital, in-band or out-of-band; etc..
  - Cryptographic - The extent to which hardware is compatible with the radio or wire system. Software must be approved for, be compatible with, and be available to all desired users.
  - Interface Connectivity - The extent to which the communications system supports each element specified in the problem definition (Module 1 - MCES) and bounded (in Module 2 - MCES).
  - Message Format and Design - The extent to which required messages meet existing criteria or that additional standards must be created.
  - Interface Operating Procedures - again, in answering the Module 1 requirements and Module 2 bounds, the extent to which all elements are in agreement as to direction and control.

4. Speed

a. Definition

Speed denotes timeliness in the flow of information between users of communications [Ref. 8: p. 2-5]. *Speed* is a communication element measure of performance supporting the *timeliness* measure of effectiveness of the C^2 system.

b. Discussion

A quantitative measure of speed is based on operational urgency. Speed is usually defined for digital systems in terms of bits-per-second (BPS) or baud rate. It is dependent on the communications means chosen and the efficiency of technology and design. Speed is also controlled by procedures. Personnel training and adherence to precedence as well as other message designators may impact communications speed. In addition to BPS and Baud rate, speed may be determined by: throughput, switching rate, routing plan, human message handling speeds, dialing method, precedence levels, processor speed and capacity; and, queueing [Ref. 7: p. A-26].

Grade-of-Service (GOS) for switched (circuit, message, and packet) systems, indicating a probability of a call (message) being blocked or delayed more than a specified interval, could also be used as a measure of speed. GOS varies from subjective ratings such as excellent, good, fair, poor or unsatisfactory, to quantitative probability calculations based on the following generalized equation [Ref. 7: p. A-24].

GOS = f(T,C,R,A,D) where:
T = traffic volume by type of service (in erlangs)
C = channel capacity
R = alternate routing capability
A = call or message arrival probability distribution (assumed to be poisson distributed for commercial communications)
D = channel degradation

c. Conclusion

The following elements may be used in supporting speed as a measure of performance:

- Overall Required Speed (measured in time)
    - BPS or Baud Rate Required
    - Throughput
    - Switching Rate
    - Routing plan
    - Human message handling speeds
    - Dialing method (touch-tone, rotary or operator assist)
    - Precedence levels
    - Processor speed and capacity
    - Queuing
    - GOS required

5. **Security**

a. Definition

Security is the protection resulting from all measures designed to deny unauthorized persons information of value which might be derived from the possession and study of communications, or to mislead unauthorized persons in their interpretation of such a study [Ref. 8: p.2-4].

b. Discussion

The four elements of communications security (COMSEC) are: crypto security, transmission security, emission security and physical security.

Crypto security results from the provision of technically sound cryptosystems and their proper use [Ref. 8: p.6-19]. In acquisition of communications

systems this involves working closely with the National Security Agency (NSA), the certifying authority for new systems applications. Crypto security measures may impact interoperability. As an example, a crypto system in use on one type of HF radio may not be approved for use with a new design. While all of the other compatibility measures may match, a requirement for a new crypto system seriously impairs interoperability, perhaps rendering the new design unsuitable. The requirement for crypto security may also degrade flexibility. Cryptographic material, both hardware and software, is issued with the realization that only loss of the software will compromise the system and then only for the period the software is in effect. Consideration must be given to the area in which the equipment will be employed. Use in a hazardous region may require limited distribution or minimal holding of the material impacting system flexibility. Alternatively, a system applying a remote keying scheme may be more costly and require more training to operate, affecting simplicity and economy.

Transmission security results from all measures designed to protect transmissions from interception and exploitation by means other than crypto analysis [Ref. 8: p.6-22], commonly referred to as LPE/LPI (Low Probability Exploitation/Intercept). Limited exploitation relates to the cryptographic capability to mask the information content of the transmission. This is often measured by the amount of time necessary to decipher the text without a key. The limited probability of intercept measures the range within which an enemy must be in order to detect and intercept a signal. This implies knowledge of the enemies capabilities and intentions and/or predicted future abilities which should have been considered in the Problem Formulation and System Bounding stages of the MCES. In determining the probability of intercept or effect on a communications system, planners will use such parameters as; range (from enemy jammer/receiver), transmit power (jammer and/or friendly transmitter), type of signalling and modulation, receiver allowed bit-error-rate (BER), antenna design, and propagation factors (including terrain).

Emission security refers to that component of COMSEC resulting from measures taken to deny information of value that may be derived from intercept and analysis of emanations from crypto equipment and telecommunications systems [Ref. 8: p. 6-26]. Care must be taken in systems design to reduce unintended emanations from tactical equipments. Such signals may appear as electromagnetic radiation from constant key sources, conducted emanations, powerline modulation, or

acoustic emanations. All are susceptible to interception and exploitation either to disclose classified information, to allow direction finding of transmitter sites, or to permit identification of electronic order of battle fingerprints of headquarters elements. Adherence, by both designer and operator, to TEMPEST requirements, established by NSA, should effectively reduce the unintended emanations. Simulation and operational testing of a proposed system coincident with existing systems should aid designers and operators in identifying and overcoming architectural weaknesses relative to emission security.

Physical security refers to the component of COMSEC resulting from all physical measures taken to safeguard classified equipment, material, and documents from access to or observation by unauthorized persons [Ref. 8: p.6-27]. Physical security, like crypto security, impacts the design process relative to flexibility and economy. The requirement to safeguard systems and software may impact universal usage and/or drive acquisition costs past on acceptable level.

c. Conclusion

The following parameters may be used in describing security as a measure of performance:

- Overall Security Requirement
    - Economic (Cost) constraint
    - Crypto (hardware/software compatibility) requirement
    - Required probability of intercept/exploitation
    - Known or projected enemy capabilities
    - TEMPEST requirement(s)

6. **Flexibility**

a. Definition

Adaptable to change (Random House Dictionary). The ability to support a wide dispersion of units under adverse or varying conditions [Ref. 8: p. 2-5].

b. Discussion

The Marine Corps definition is limited in that it implies a universal use and is directed more towards the planning and integration of *all* systems to support command and control. It requires acquisition sponsors to consider the combined effects of proposed and existing systems and to study the results of operational tests before committing to full-scale production.

Because of the versatile nature of modern warfare, flexibility also infers mobility, or the ability to retain command and control while on the move. This influences size, weight and transportability of equipment, personnel and logistics to support the system.

The dictionary definition indicates an ability to change by expanding, contracting or reorganizing the service provided. It may also allow change of modes within a specified range of operation. For instance; an error control may be relaxed for digitized voice and increased for data transmission. Or, in order to improve emission security, transmission power may be tunable to the least amount necessary to ensure reception limiting the range of interception.

c. Conclusion

Flexibility determinants include:

- Ability to expand, contract, or reorganize service
- Choices of bit rate
- Choice of transmitter power
- Choice of error control
- Mobility factors

7. Survivability

a. Definition

All measures taken to prevent disruption of communications by 1) enemy interference or natural disaster [Ref. 8: p. 2-7] and, 2) measures the capability to survive conventional, nuclear and CBR attack for continuity of operation under the worst probable conditions of conflict [Ref. 7: p. A-8].

b. Discussion

As a function of the sum of the aforementioned factors, the survivability measure must be evaluated as constrained by budgetary considerations.

Disruption by enemy interference has been covered, albeit obliquely, under transmission security. The same parameters, ie., range, transmit power, type of signalling and modulation, BER, antenna design, and propagation factors, are used to determine the effect of communication jammers. The use of similar design parameters do not adversely affect measure independence. The equations used to derive the measures are unique.

Measures to prevent natural and or man-made disaster include such elements as redundancy (outlined under Reliability) and design. Design criteria

describe the physical characteristics of equipment necessary to withstand chemical, nuclear and conventional damaging effects. Such requirements inherently drive-up costs as physical properties are reinforced and electronic components are built or backed-up to withstand the affects of electromagnetic pulse (EMP).

Survivability is also enhanced by the Mobility factors listed under Flexibility.

c. Conclusion

Survivability determinants include:

- Overall Survivability Requirement
  - Economic (cost) constraint
  - Redundancy (Number of backups required)
  - Range
  - Transmit power
  - Signalling and modulation
  - BER
  - Antenna design
  - Propagation factors (including terrain and weather)
  - Mobility factors

8. **Simplicity**

a. Definition

The ease of access and operation for users, and the ease of installation, operation and maintenance for operators [Ref. 8: p. 2-7].

b. Discussion

Simplicity, easy to define, is becoming characteristically ignored in new systems development. The technology that allows a reduction in operations manning, at times, increases the demand on communications managers and personnel. Thus, from both budgetary (in terms of manpower) and simplicity perspectives, trade-offs must be made in order to find the optimum mix between operations and communications.

Simplicity may also affect flexibility. A flexible system, one with many options, may be complex to operate and maintain, yet meet the definition demands of Module 1 (MCES).

c. Conclusion

Simplicity considerations include:

- Simplicity requirement; balanced against,

- Budgetary (Manpower training) impact
- Flexibility and mission need statements

9. Economy

a. Definition

Economy results from actions taken to ensure the best use of available communications personnel, equipment and supplies etc.(Random House Dictionary).

b. Discussion

While previously mentioned as a constraining parameter for other measures, economy, or a degree of economy, should be considered as a measure itself. Given a cost constraint, the acquisition manager must balance the bounded mission need against the cost of acquiring the measures necessary to support the requirement. Hence, the budget is compared with the sum of the costs of supporting each measure. Simply put, if cost exceeds budget, the manager must justify a request for increased funds, reiterate the MCES process, or recommend project cancellation or re-definition.

c. Conclusion

Economy requires conciliation between the project and existing demands for scarce resources (money, personnel and equipment). Given a budgetary or cost restriction, the decision maker must make every effort to stay within these guidelines while ensuring, first and foremost, that the mission requirement (Module 1) is resolved.

E. MEASURE INTERACTION

The introduction to the previous section alluded to *potential* interrelationships between measures. Figure 3.1 graphically portrays these associations. The dependencies or connections are represented by the lines drawn between the measures. Arrows indicate flow. While it may certainly be debated that all measures are related, one to another, the links shown depict the author's subjective judgement of the most important effects. Other analytical means, beyond the scope of this thesis, are needed to determine degrees of interaction. Sensitivity analysis or a database of past experience are two possible ways to define measure interplay.

F. CONSIDERATIONS

Numeric values approaching 100% are desired for some of these measures (reliability, interoperability, security, flexibility and survivability). While verbal merits such as "fastest" (speed), "least expensive" (economy), and "uncomplicated" (simplicity) would describe others. However, use of such terms is not only impractical but

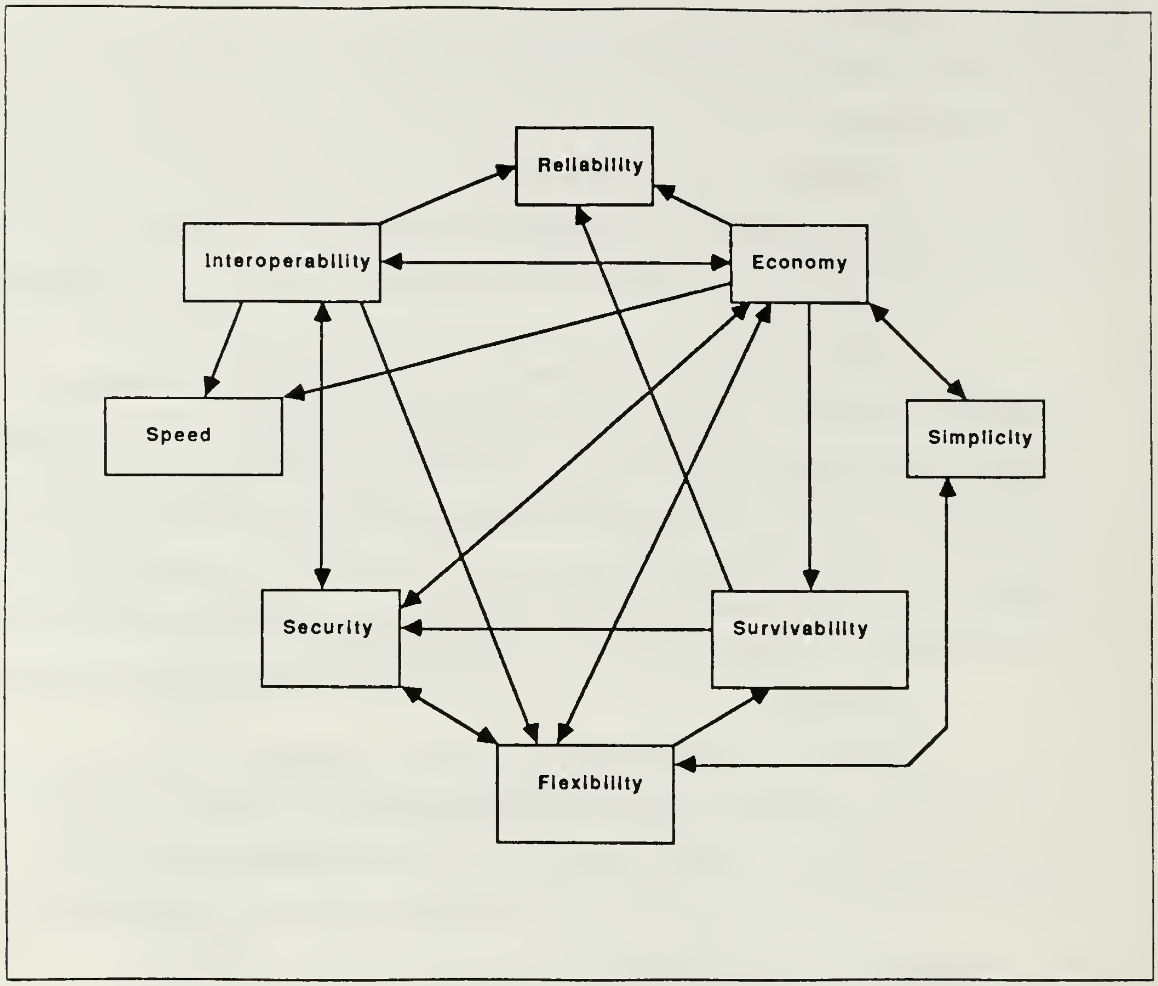

Figure 3.1 Measures Interactions.

unattainable. When specifying these measures, consideration must be given to their underlying parameters and overall system requirements. For example, while it may be nice to have a system that will operate at 5 megabits-per-second, to cover every eventuality, if the computer processing speed at the terminal's input and output is 1000 bits-per-second, too much slack has been required in the variable. Relative to the previous discussion, this may adversly affect cost with no necessitated gains. In short, the quantitative or qualitative descriptions required must represent reality.

Another consideration involves a standard, or nearly standard means of attaining values for measures. The Marine Corps' Technical Interface Concepts (Chapter V) represents an attempt at regulating this process. By describing the statics involved, the process between elements, and comparing these with existing integrated systems, the

process becomes regulated. Anomalies require justification for addition to existing databases. Similarities aid in starting the process of detailed requirements listings. If, for example, a similar task (process) is required of other elements (statics) within the database, decomposition may well lead to physical properties already used to support such a function. These values lend a starting point for requirements. More important, the point is already employed by the organization, in this case The Marine Corps, and adherence to such a level, while perhaps not imperative in this specific application, may well serve to assist future endeavors. Suppose the message standard leads to a bandwidth specification of 5 Mhz impacting speed, reliability, security, and economy (for this example). While not a critical or required measure in this case, the designated parameter affects (positively) interoperability thereby allowing for possible expansion of the desired system into other applications.

Relative importance of measures at the acquisition management level is dependent ultimately, and optimally, on support of the mission need described in Module 1. This is determined, in the final analysis, on performance under actual operating conditions. However, decisions involving performance and effectiveness must be made much earlier in the process. Lacking 'fool-proof' means of weighting measures, the decision maker must make, at times subjective, judgements as to associated merit. This may again require an iterative process. Political reality currently mandates interoperability, reliability, and economy as critical measures. A 'generic' ranking is certainly unwise and description of decision theory is beyond the scope of this thesis. One means, or consideration, is certainly worth mentioning. While seemingly self-evident, the decision maker must assure amelioration of both operator and systems engineers in the process. Failure to consider the input of one or the other may lead to disastrous consequences.

Two final points need to be stressed. While the measures (MOPs in this case) may be interrelated, the equations used in defining them are not. The parameter 'range' may be used in determining both 'speed' and 'security'. However, the formulation of these must be kept separate. Mathematically, while security may be a function of range (security = f(range,...)) and speed is a function of range (speed = f(range,...)), the functions are unique even if the design parameters are equal.

Finally, both quantitative and qualitative standards have merit in the analysis. While numeric values may be desirable, they are not always attainable. Verbal descriptors may point to debate and subjective judgement; however, a measures' merit

is *not* to be based on an ability to assign an arithmetic rate. The measure is necessary because it aids in characterizing the system. Omitting qualitative measures would result in an incomplete description.

G. SUMMARY

This chapter has defined and described generic measures of performance to be used in analysis of a communications system. As part of the description, a listing of parameters was derived to support derivation of each measure. Table 4 reflects the results. While perhaps not all inclusive, it represents a point of departure for system analysis.

TABLE 4
GENERIC MEASURES

Measure	Parameters
Reliability	Component MTBF, Redundancy, Receive Sensitivity, ReceiveSelectivity, Transmission Efficiency,Required BER, Mean Time to Repair
Interoperability	Modulation, Frequency Range, Range, Signalling, Cryptographic, Interface Connectivity, Message Format and Design, Interface Operating Procedures
Speed	BPS or Baud Rate Required,Throughput, Switching Rate, Routing Plan, Human message handling speeds, Dialing method, Precedence levels, Processorspeed and capacity, Queuing, GOS Required
Security	Economic (cost) constraint, Crypto (hardware/software compatibility) requirement, Required probability of intercept/exploitation, Known or projected enemy capabilities, TEMPEST requirement(s)
Flexibility	Ability to expand, contract, or reorganize service, Choices of bit rate, Choice of transmitter power, Choice of error control, Mobility factors
Survivability	Economic (cost) constraint, Redundancy, Range, Transmit power, Signalling and modulation,BER, Antenna design, Propagation factors, Mobility factors
Simplicity	Budgetary (manpower/training) impact, Flexibility and mission need statement
Economy	Conciliation between the project and existing demands for scarce resources.

IV. TECHNICAL INTERFACE CONCEPTS

A. INTRODUCTION

> Powerful, sophisticated, command and control (C2) systems that exploit a rapidly expanding technological base are becoming realities; yet, issues concerning their integration into the larger context of a command and control architecture remain unresolved. Military planners require clearly defined standards of compatibility and interoperability to retrofit fielded systems, modify those currently in design, and plan for future ones. A major goal of the Department of Defense is to provide these planners with accurate, detailed information about their particular system requirements, about the interrelationship of their tactical system with other systems, and about the impact that system will have on the architecture as a whole.
>
> Achievement of this goal requires development of a suitable method for identifying, capturing, organizing, and accessing information necessary to describe current and projected systems. Succinctly stated, the military must develop a usable model of its C2 architecture. This model must provide two essential premises. First, it must answer detailed questions about the C2 structure, providing a view of that structure in its totality as well as its particulars. Second, it must provide input to programs engaged in dynamic analysis such as wargame scenarios and network loading studies [Ref. 10].

This quote provides a concise statement of DoD and Marine Corps' objectives relative to managing command and control architectures. Most of the references cited in this chapter have to do specifically with inter and intraoperability, yet in standardizing interoperability and acquisition management processes and responsibilities, it also provides a systematic mechanism for compliance with the bounding, process definition, integration, and data generation modules of the MCES. This chapter will describe the Technical Interface Concepts (TIC) and Marine Corps Interoperability Management Plan (IMP) principles applicable in the MCES framework pertinent to communications acquisition and management.

B. PURPOSE

The overall objective of the Interoperability Management Plan (IMP) is to ensure the exchange of critical tactical information. This is accomplished at two levels: first, on a Marine Corps unique level (referred to as intraoperability) then, on a joint or combined level between Marine Air Ground Task Forces (MAGTFs) and other U.S. or Allied commands. The IMP centralizes and standardizes procedures for management activities. These procedures aim to accomplish the following:

- Identify the manner in which existing and new interoperability requirements and standards are identified, defined, standardized, and documented.
- Facilitate the implementation, verification, testing, and certification of those standards in developing tactical data systems (TDSs) and interconnecting equipment.
- Prescribe coordination between the various configuration management bodies and activities that control modifications to requirements, standards, TDSs, and interconnecting equipment.
- Ensure that interoperability program requirements are adequately planned for and funded [Ref. 11: p. 1-3].

The Technical Interface Concepts (TIC) document identifies and establishes Marine Corps command, control, and communications (C^3) facility and systems operational interface requirements for both current and future periods. It is a baseline from which other USMC interoperability technical documents, standards, and specifications are developed [Ref. 12: p. 1-1]. The objective of the TIC is to provide the framework to ensure that fielded Marine Corps Tactical Command and Control Systems (MTACCS) are compatible, interoperable, and operationally effective. In keeping with the IMP, MTACC systems are first intraoperable, then interoperable with other than Marine systems. Compatibility with other service systems is to be attained through application of the JINTACCS (Joint Interoperability of Tactical Command and Control Systems) program.

C. PHILOSOPHY

The MTACCS concept of standardizing automated interfaces has been to : (1) standardize at the "transmission format" level, (2) leave the man-machine interface to be resolved by individual system requirements and constraints, and (3) to bit-code messages and data items. The JINTACCS concept has evolved to one of standardizing: (1) both at the machine and human levels, (2) for voice, record, and automated interfaces, and (3) character codes for data items. In order to maintain compatibility in JINTACCS Allied operations, MTACCS systems engineering has maintained compatibility at the data item level and developed message conversion protocols for specific interfaces [Ref. 12: p. 1-2].

D. METHODOLOGY

This section will address the specific set of procedures designed to determine specifications and standards from validated operational (or mission) requirements. The mission requirements formulation is the responsibility of Mission Area Sponsors. These sponsors conduct Mission Area Analyses (MAAs) in an effort to validate

current requirements and to define future operational needs. A command and control architecture is then developed to facilitate the aggregation of associated elements required to support mission needs. The basic entities of a C^2 architecture are illustrated in Figure 4.1 (author's concept) and described below [Ref. 11: p. 3-3].

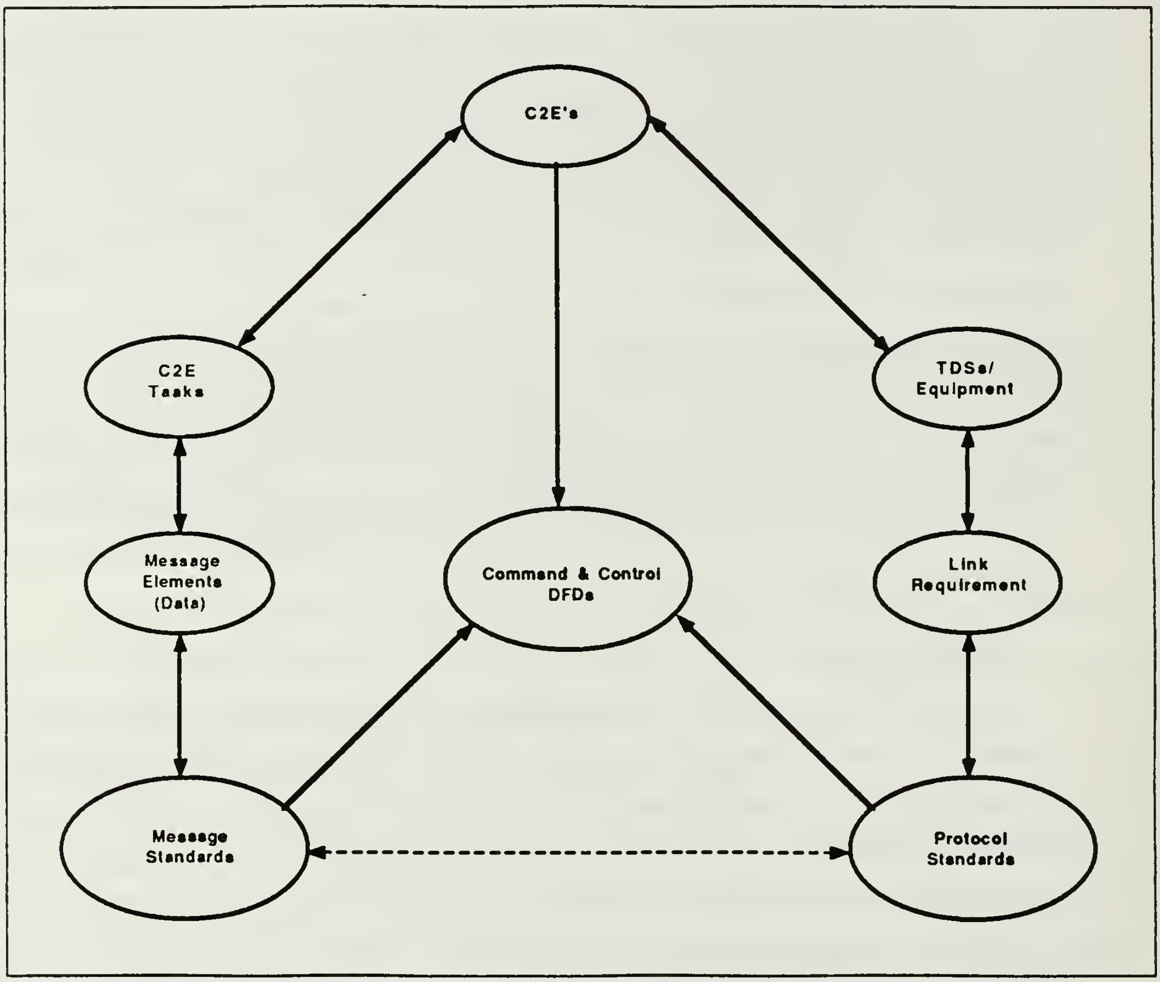

Figure 4.1 Marine Corps C^2 Architecture.

1. Operational Facilities

Otherwise referred to as C^2Es (Command and Control Elements) in the parlance of Joint planners, Operational Facilities (OPFACs) are those elements tasked with performing the C^2 Process functions described in Chapter II (Table 4). Each C^2E consists of equipment, communications, facilities, personnel, and procedures required to assist the commander in carrying out his C^2 responsibilities. They vary widely in

size and complexity from a single forward observer (FO) to a large, integrated Fire Support Coordination Center (FSCC).

2. **Tasks**

OPFAC or C^2E tasks are those functions performed by the C^2E requiring it to exchange information with other C^2Es. They are extracted from existing documents reflecting approved doctrine, procedures and techniques contributing to the overall command and control function.

3. **Message Elements/Standards**

Elements are the fundamental details of information used to construct messages. Message elements are composed of standard Data Field Identifiers (DFIs), Data Use Identifiers (DUIs) and Data Items (DIs). These standards are used to implement information exchange in Marine Corps TDSs. The elements are collected and formed into standard messages and documented in the Technical Interface Design Plan (TIDP).

4. **Equipment and Link Requirements**

C^2Es relate to one another as either source or sink (sender or receiver) of the messages described above. This relation implies a requirement to establish a communications link in support of information flow. The link is established using TDS's interconnected with communications equipment, each of which can be characterized by their functions. Communications links are defined in terms of operational characteristics and constrained by technical factors. Ultimately, the link requirements are specified in terms necessary to support mission needs. Compliance with these needs allows specific description of the link and its associated equipment.

5. **Protocol Standards**

Protocols are the rules or procedures by which information is transferred through systems, interconnecting equipments, and networks. Marine Tactical System (MTS) protocols are defined by an eight-layered reference model beginning with the transmission media and ending with user application. The model and standards are documented in the TIDP.

6. **Message Exchange Occurrences**

A command and control architecture is typically represented as a Data-Flow-Diagram (DFD). The circles representing nodes and the connecting lines communications links. A specific node in a C^2 network may be comprised of one or more C^2Es. For example, an Infantry Battalion node may be made up of Fire Support

Coordination Center (FSCC) and Combat Operations Center (COC) C^2Es. In keeping with the previous discussion of architectural elements, the lines must also represent messages to be transmitted along the link. Without the message requirement the link is idle. The most basic network, then, consists of two C^2Es, a link, and a message that transports information along the link. This relation is portrayed in Figure 4.2. Limiting the description further, to the transmission of a single message, requires a discrete information transfer. This is termed a Message Exchange Occurrence (MEO). Validated MEOs establish a requirement for interoperability and at the same time a system requirement in support of the basic mission need.

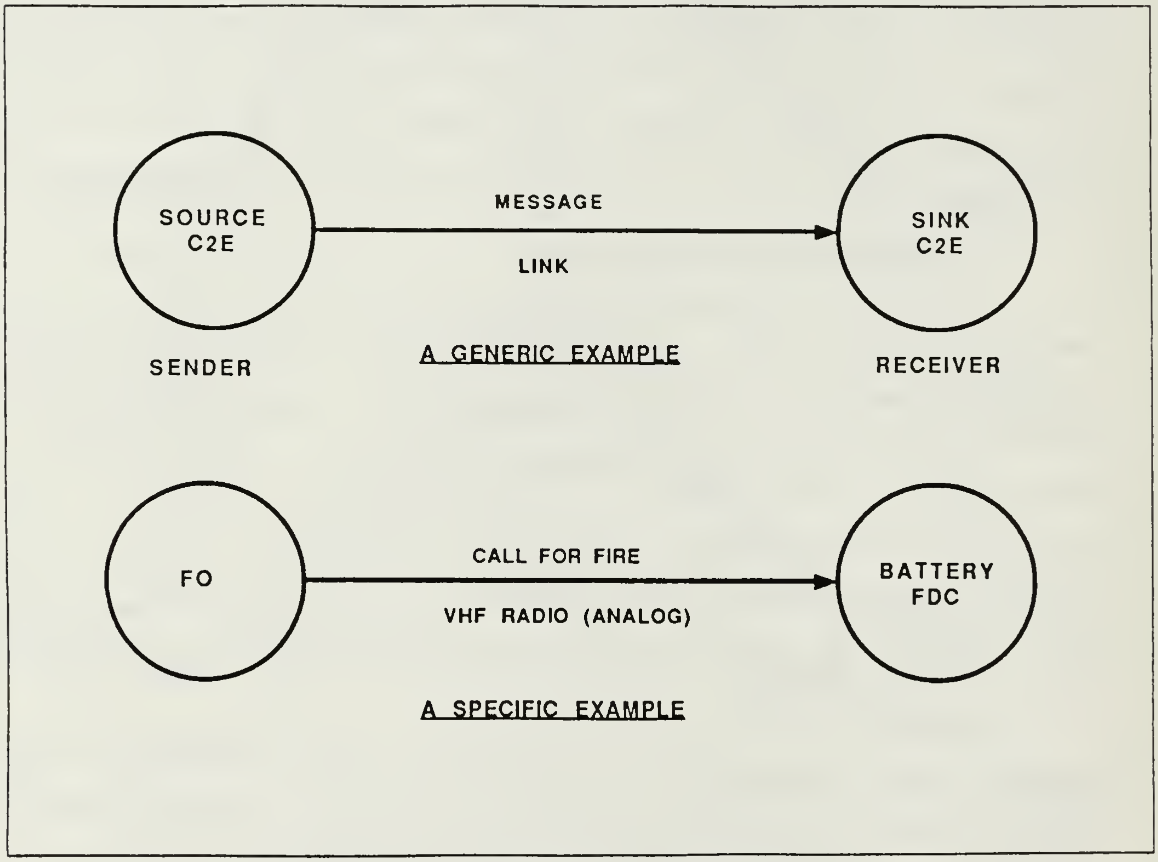

Figure 4.2 Message Exchange Occurance.

E. IMPLEMENTATION

A listing of all validated MEOs is useful in portraying an architecture as it exists in its "potential" state. In order to model the C^3 process in a specific "kinetic" state,

order must be subscribed to the MEOs describing flow of C^2 activity as a sequence of events [Ref. 10]. The modelling process is illustrated in Figure 4.3. The model can be used to define specific measures of effectiveness and then validate the system support of mission need. Even a superficial understanding of military structure would suggest to the reader that a listing of MEOs is quite extensive. This section will explain how MEOs are derived, used to build a network, and used to model command and control. This description follows closely the work of Pipho [Ref. 10].

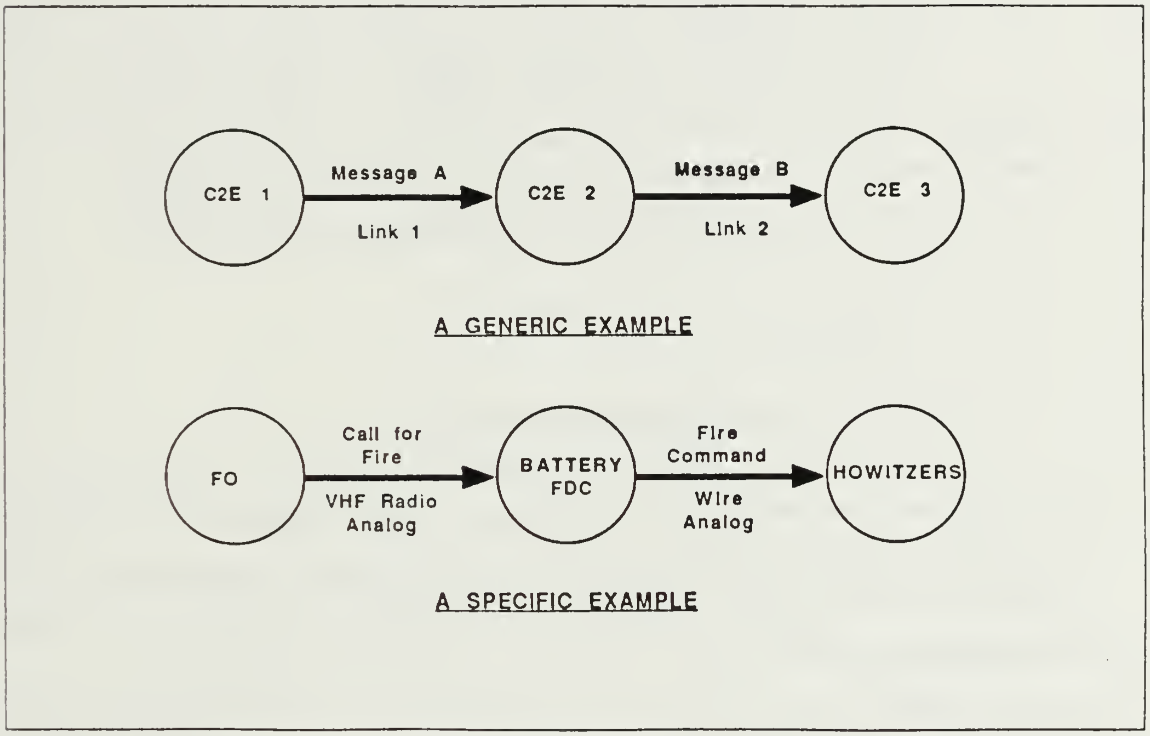

Figure 4.3 MEO Chain.

1. Information Base

The number of MEOs is seemingly limitless. Many pages would have to be written to effectively capture the information content of all MEOs. Screening the potential exchange capabilities and requirements to find matches or similarities for potential architectures would be a grueling task. An automated database would expedite this process improving management of both existing and potential C^3 systems.

The Marine Corps Interoperability Database (IDB) is being designed to provide improved management, integrity, and communication of inter intraoperability information. The IDB will provide the automated tools to:

- standardize and centralize inter/intraoperability data;
- manage proposed changes to interoperability requirements and standards;
- automate and manage the documentation process (TIC,TIDP);
- automate compliance tracking; and,
- coordinate between interoperability requirements and standards.

Additionally, a fully functional IDB will provide a basis for the implementation of future applications such as:

- simulation of inter/intraoperability scenarios under battlefield conditions; and,
- determine alternative communication interfaces/configurations [Ref. 13: p. 3].

The first step in developing the IDB is to identify and describe the basic components that define the C^2 architecture. Then the relationships that exist between these components are specified and entered into the base of information.

At the most general level, the C^2 architecture components are:

- C^2Es (OPFACs)
- C^2E tasks
- C^2E resources
- Information required to perform C^2E tasks
- Communication capabilities to support the exchange of information [Ref. 10].

Each of these have been previously described. Figure 4.4 shows this set of components and their relationships. C^2Es have two kinds of resources: people and equipment. The degree to which people or equipment are employed depends on the degree of automation involved.

2. Process

The Data Flow Diagram (DFD) is the primary tool used to illustrate the major components of the IDB and to systematically decompose major functions to their basic level. The function being described is the MEO. Its elements include: the C^2E, message, and link.

a. Deriving C^2Es

C^2Es are identified by name, location within the organization, and by tasks they perform. Titles, such as "fire direction center," simultaneously identify the Element and give some idea of their function. These titles become progressively more descriptive, identifying branch and echelon (e.g. infantry regiment fire direction center) and joint or combined level (including service and nation). A C^2E is specified, then, by organization (or unit), branch, echelon, service, and country.

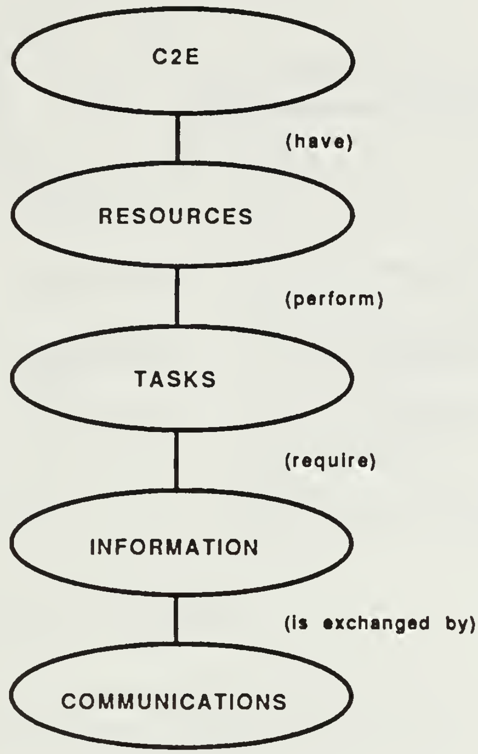

Figure 4.4 Components of C^2 Architecture and Their Relationships.

The C^2E is the processing component of the system. It performs a transfer function processing input and changing it to output. This process is illustrated in Figure 4.5. The Input-Process-Output (IPO) function is presented as both information and signal processing.

b. Deriving Message Standards

A C^2E is viewed, then, as a C^2 system component whose function is to process information. One C^2E may receive raw intelligence information in an incoming message. This information is processed by extracting pertinent information in terms of an intelligence assessment. This assessment is then distributed to other C^2Es as an update in an outgoing message. The transfer function can be described in terms of the tasks being performed. An analysis of these tasks suggest the information required by the processing C^2E. A decomposition of a C^2E task results in a set of subtasks that retain the basic IPO structure at a lower level. Just as information

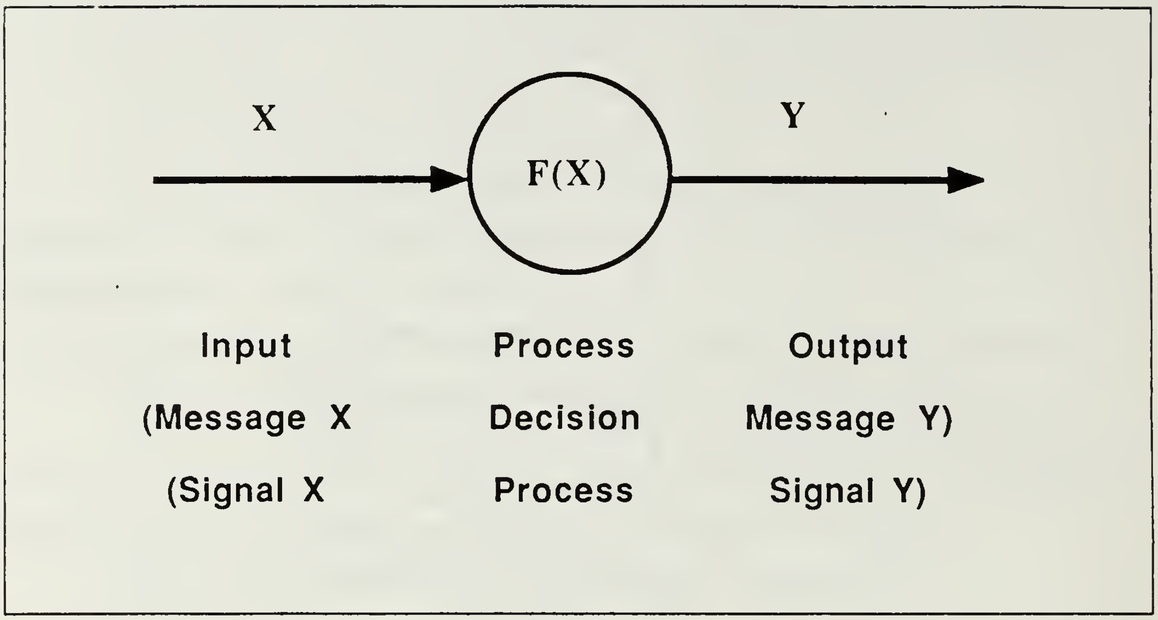

Figure 4.5 IPO Model.

packaged in a message feeds the general task, information elements feed the C^2E subtasks. these elements can be correlated with standard message elements. The set of message elements reflects the information requirement necessary for all the subtasks reflected in the general task. By labeling this set, an appropriate message standard is specified.

To illustrate the decomposition process, consider a hypothetical situation in which a tactical air operations center (TAOC) must alert a light anti-air missile (LAAM) battalion combat operations center (LAAM BN COC) to the possibility of engagement with enemy aircraft. The TAOC must determine what message will convey completely the information required by the LAAM BN. A tactical alert will invoke a set of procedures at the LAAM BN COC. The COC must perform the subtasks listed in Table 5. These tasks govern the information required from the TAOC. Using the Marine Corps Message Element Dictionary (MED), standard elements of information can be derived, called Data Field Identifiers/Data Use Identifiers (DFI/DUI)(Shown in Table 6).

If this particular combination of standard message elements is in the Marine tactical system's message inventory, it should be used. If not, the required elements are enumerated and submitted as a proposed standard for this particular tactical function.

TABLE 5

AIR ALERT SUBTASKS

SUBTASK NUMBER	SUBTASK DESCRIPTION
Subtask 1	assign a track number to the tactical alert
Subtask 2	classify the alert in terms of its track type
Subtask 3	record the time of the event
Subtask 4	classify the aircraft in terms of threat type
Subtask 5	estimate flight size
Subtask 6	record the bearing
Subtask 7	record the range
Subtask 8	record the altitude
Subtask 9	record the velocity
Subtask 10	issue command instructions

TABLE 6

DFI DUI BREAKDOWN

INFORMATION ELEMENTS	CORRESPONDING DFI/DUI
Track number	E618/001
Track type	E090/001
Threat time	C051/165
Threat type	E529/001
Flight size estimate	E901/001
Track bearing	E494/011
Track range	E499/003
Track altitude	E491/170
Track velocity	E233/001
Command action	E905/001

If the task description is incomplete, the user or cognizant doctrinal agency initiates action to correct it. This assures that operational requirements drive message standards.

c. Deriving Link Standards

Information is generally transmitted to a C^2E through an electronic signal. The message (Text) is entered into a converting device at the input, changed to electronic format and passed through a string of equipment to the next C^2E. Here it is translated into the original textual form. Input and output requirements for each electronic device in the string are expressed technically as equipment specifications. Matching the input text to the output text specifies compatibility for the link. Figure 4.6 characterizes the communications system and illustrates signal interface requirements. By correlating the specifications of a system with these standards, the signal interface requirements are satisfied. The technical specifications define the standard for the C^2E link. An occurrence of this link is recorded in the MEO.

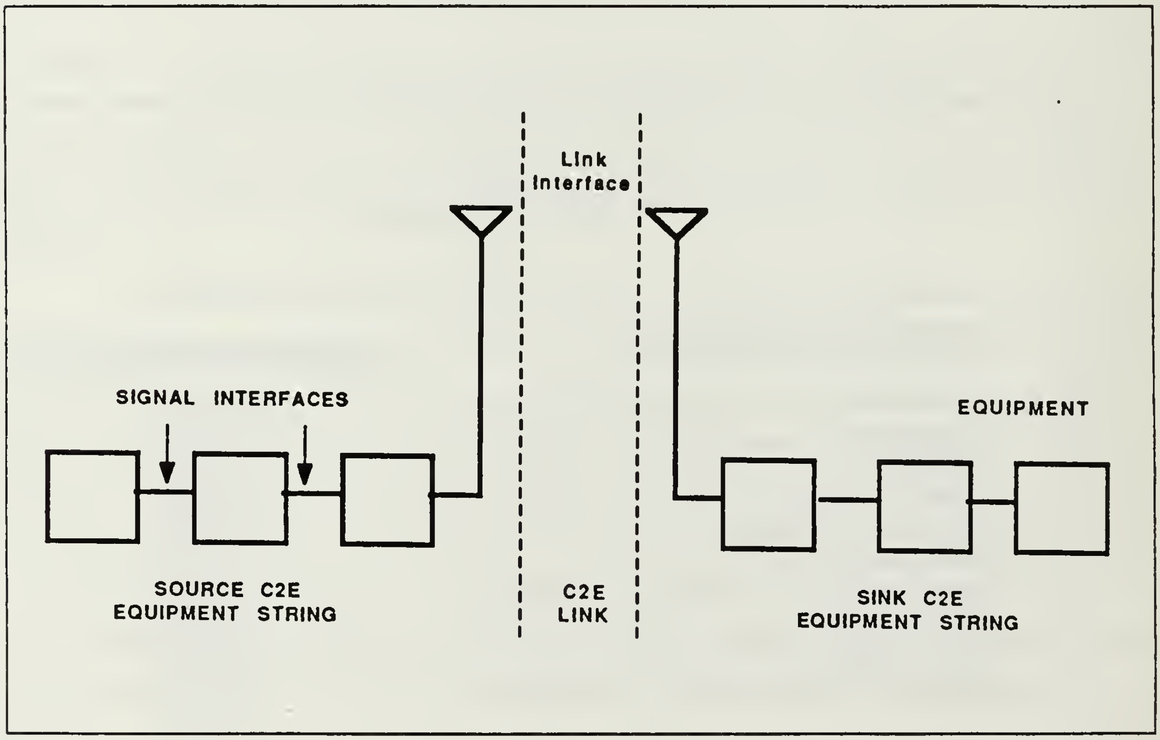

Figure 4.6 Communications System.

C^2E links are usually constrained by the environment and context dictated in the mission requirement. These operational factors include determinants like range and security. These restrictions also help refine the technical specifications leading to a C^2E link standard. Requirements are successively broken down into lower levels of detail through engineering analysis. If no system or equipment set exists to support the link requirement a circuit standard is adopted as a set of design specifications for the system.

3. Network Construction

The MEO is the basic network building block. A complete set of MEOs produces the C^2 Network. The proper association of MEOs is crucial to the construction of a network to be used as the model for command and control. While the MEO, by definition, describes a direct transfer of information, at times the exchange may transpire between non-adjoining C^2Es. To accommodate this eventuality, the concept of a virtual message exchange occurrence (VMEO) is introduced. The VMEO denotes a path from the source C^2E to the sink C^2E through one or more intermediate C^2Es. In essence the VMEO is simply a chained MEO as shown in Figure 4.3.

Command and control flow diagrams (C^2FDs), a specific application of data flow diagrams (DFDs), are constructed using the doctrinal studies described in mission area analysis. The C^2FDs represent pictorially the flow of C^3 activity in the network. Figures 4.7 and 4.8 combined with Tables 7 and 8 summarize the network design process.

F. SUMMARY

The interoperability database will provide a valuable tool for planners and managers to standardize description of the Marine Corps command and control architecture. Consistent application of the MEO concept in the IDB will help ensure interoperability and, at the same time, should reduce the procurement of redundant C^3 systems. Driven by mission needs, the Technical Interface Concepts is in keeping with DoD direction discussed in Chapter II under Problem Formulation. The use of Message Exchange Occurrences follows closely the system bounding, process definition and integration modules of the MCES. Finally, the MEO description available in the IDB allows for data generation (Module 6) and aggregation following the outline of System Effectiveness Analysis which follows.

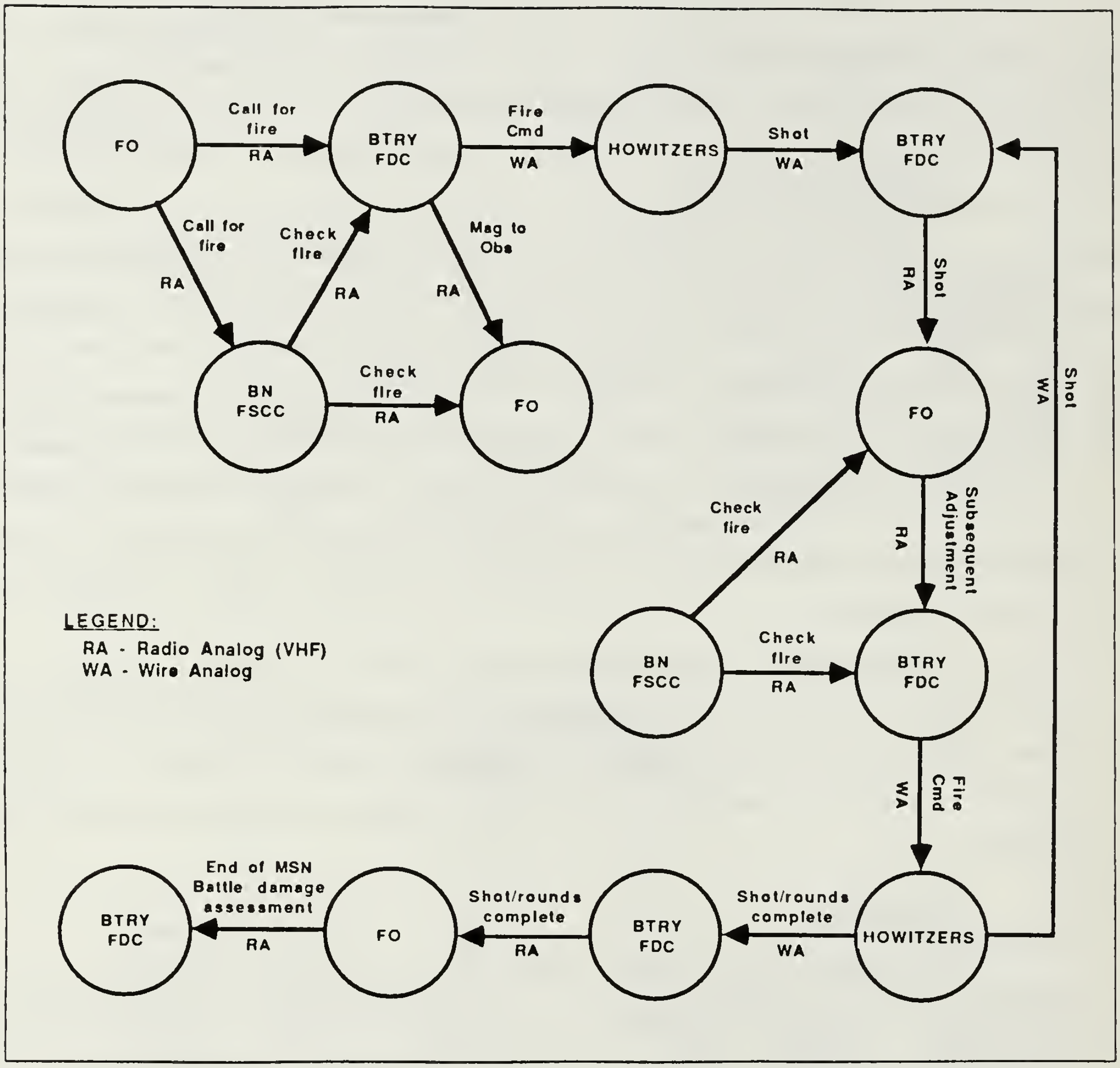

Figure 4.7 C^2FD for Direct Support Artillery Mission (DSAM).

TABLE 7

MEO SET FOR DSAM

MEO	SOURCE C2E	SINK C2E	MESSAGE	LINK
1	FO	BTRY FDC	CALL FOR FIRE	VHF RADIO
2	FO	BN FSCC	CALL FOR FIRE	VHF RADIO
3	BTRY FDC	HOWITZERS	FIRE CMD	WIRE
4	BTRY FDC	FO	MSG TO OBS	VHF RADIO
5	HOWITZERS	BTRY FDC	SHOT	WIRE
6	BTRY FDC	FO	SHOT	VHF RADIO
7	FO	BTRY FDC	ADJUST	VHF RADIO
8	BN FSCC	BTRY FDC	CHECK FIRE	VHF RADIO
9	BN FSCC	FO	CHECK FIRE	VHF RADIO
10	HOWITZERS	BTRY FDC	RNDS COMPLETE	WIRE
11	BTRY FDC	FO	RNDS COMPLETE	VHF RADIO
12	FO	BTRY FDC	END OF MISSION	VHF RADIO

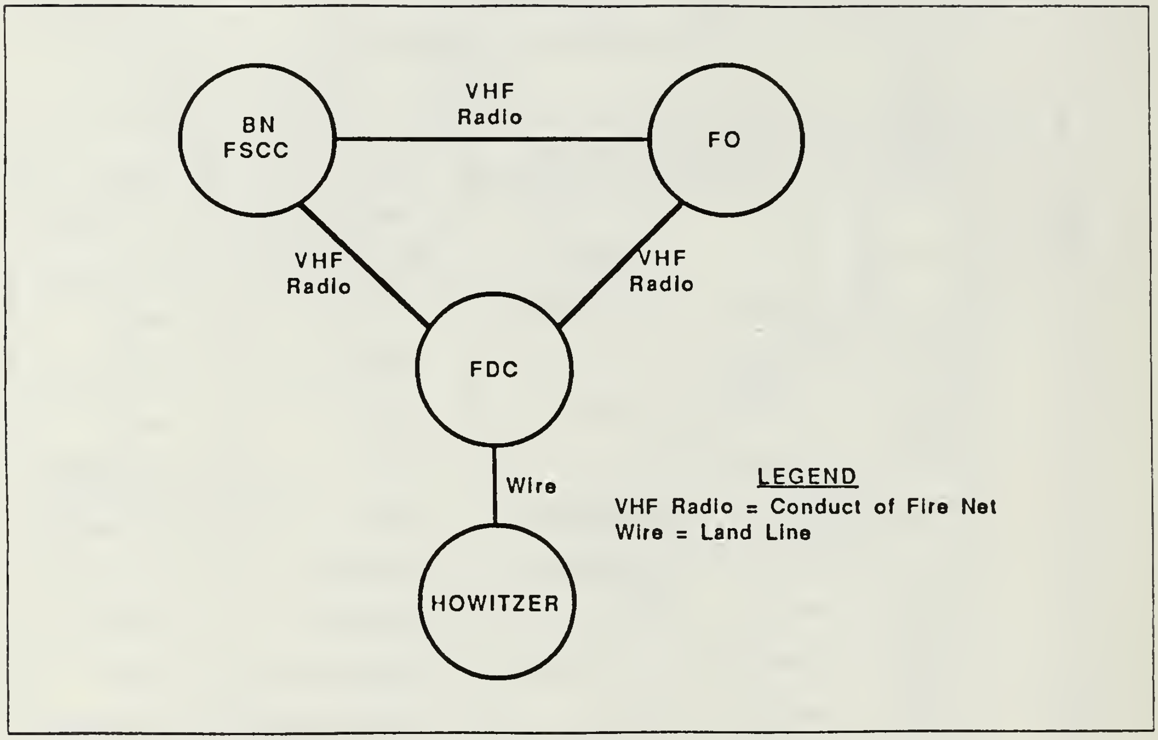

Figure 4.8 Network Derived From MEO Message Set For DSAM.

TABLE 8

SUMMARY OF NETWORK DESIGN PROCESS

STEP 1: Establish the operational requirement.

a. Establish the command and control requirement.

(1) Identify C2Es by:
   (a) Name
   (b) Tasks
   (c) Location within the command and control structure

(2) Draw C2FDs by:
   (a) Determining the sequence of activity for the mision area
   (b) Classifying the information passed from C2E to C2E in general terms

b. Establish the general communication requirement.

STEP 2: Construct an MEO

a. Produce a message by:
   (1) Decomposing the C2E task into elemental C2E tasks
   (2) Correlating the elemental C2E task with required information elements
   (3) Correlating the information elements with appropriate data elements

b. Identify connectivity from C2E pairs.

c. Produce a C2E link by:
   (1) Deriving the link interface requirements from the communications requirements
   (2) Decomposing the link interface requirements into technical specifications

STEP 3: Design the Network.

a. Specify the MEOs that comprise a C2E interface
b. Select equipment to implement the C2E links

V. SYSTEM EFFECTIVENESS ANALYSIS

A. INTRODUCTION

The MCES, as described in Chapter II, provides a logical and orderly framework for problem formulation, system bounding and specification of measures. The Marine Corps' Technical Interface Concepts (Chapter IV) characterizes the system and functions, and integrates them. Assigning the generic Communications measures (Chapter III) quantitative or qualitative values completes the first six modules of the MCES. What remains is to aggregate parameters and/or measures and then compare them to some desired state. System Effectiveness Analysis (SEA) focuses on the quantitative aspects of obtaining and evaluating measures. The steps of SEA can therefore be embedded in MCES, specifically in the last modules (Generation and aggregation). The following is a brief history of SEA provided the author by Dr. Alexander H. Levis, Senior Research Scientist, Massachusetts Institute of Technology.

B. BACKGROUND

System Effectiveness Analysis was first tested, starting in 1977, with funding from the Department of Energy (DOE) at Massachusetts Institute of Technology (MIT). The three year project focused on large power systems culminating in a final report (Pierre Dersin) during May 1980. Thesis works conducted primarily on command and control systems include: Bouthonnier (August 1982), Cothier (August 1984), Karam (January 1985), Bohner (May 1986), and Martin (August 1986). Other applications of the methodology include work on Flexible Manufacturing Systems (Washington - January 1985) and Assessment of Internal Combustion Engines (Levis, Haupt and Andreadakis - 1985).

C. SYSTEM EFFECTIVENESS ANALYSIS

The description of SEA provided herein follows closely the work of Cothier [Ref. 14: pp. 11-17] and Levis [Ref. 15: pp. 2-11, 15-17].

The basic premise of the methodology is that a C^3 system provides a service to the commander and his forces and, conversely, the commander establishes performance requirements for the system. Or, the C^3 system possesses a range of performance characteristics and the commander specific requirements based on his assigned mission.

The analysis assumes an ability to model both system capabilities and commander's requirements in terms having the same measure. This assumption is critical for without like dimensions, the evaluation falls apart.

1. Concepts

The integration of MCES and SEA is possible because both approaches are based on the same concepts. Specifically: *system*, *environment*, *context*, *design parameters*, *measures of performance*, *and measures of effectiveness*. Of these six only the term *context* has not been previously addressed (see Chapter II). The system and environment are defined within a particular context upon which the system cannot act, but which affects the system. It describes the circumstances surrounding an event or situation. Figure 5.1 shows the relation. Figure 2.3 portrays the connection, derived for this specific application.

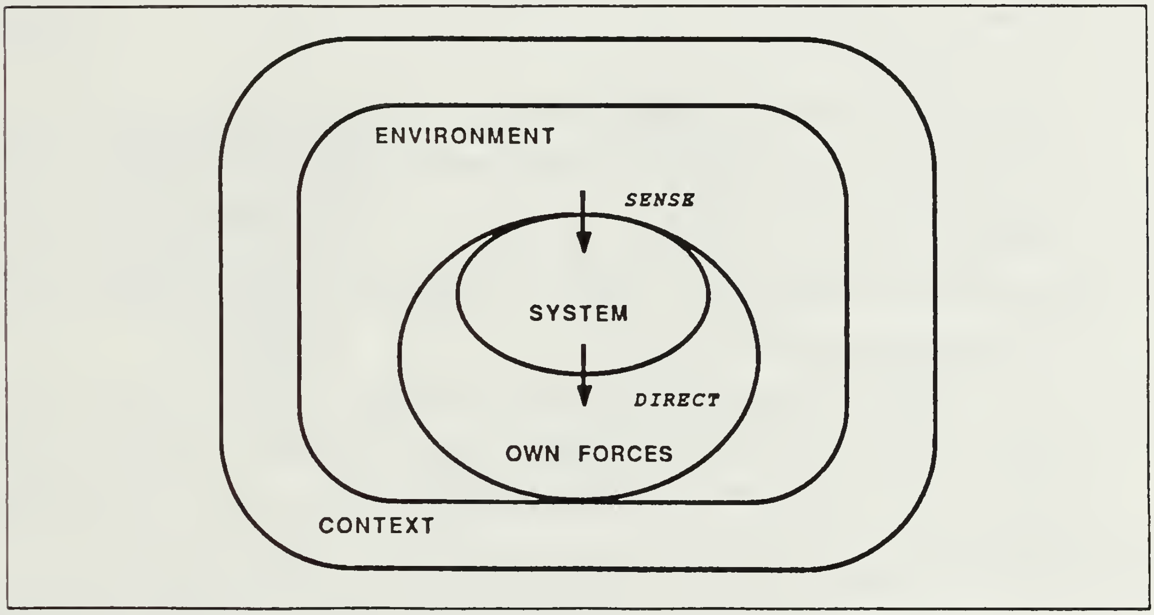

Figure 5.1 System, Environment, and Context.

2. Methodology

The mission, system, environment, and context have been defined in Modules 1 through 4 of MCES, and the Measures of Performance for a communication system described in Chapter III. The first step in SEA is to select the design parameters that influence each system MOP (also characterized in Chapter III). By definition, these parameters are considered mutually independent, since they constitute the "independent

variables" in the analytical formulation of the methodology [Ref. 15: p. 6]. The key word or element in step-one is *system.*

The second step consists of defining parameters for mission requirements. The important words being *mission* and *requirement.* Levis indicates that this step, while implied in the feedback loop, is not explicit in MCES [Ref. 15: p. 7].

In steps three and four the chosen *system* and *mission* parameters are used to define *MOPs* and *Requirements* respectively. Each are expressed as functions of their parameters, i.e.,

$$MOP_i(A_i) = f_i(x_1 \ldots x_k) \qquad \text{(eqn 5.1)}$$

where x_i are the system parameters, A_i are Attributes or MOP's; and,

$$R_m = f_m(y_1 \ldots y_n) \qquad \text{(eqn 5.2)}$$

where y_i are the mission parameters and R_m are mission requirements. The issue of independence, previously addressed, is also applicable for the A's and R's derived from the formulation. Yet as dependent variables, they may be interrelated through use of common parameters. Hence, trade-offs in one area may impact others. The results of these steps are specification of value(s) for both MOP and mission reflected as points or regions in their respective spaces.

While both spaces may be of the same dimension, they could be defined in terms of different quantities or quantities scaled differently. Step five consists of transforming the dimensions into like quantities to be defined on a common coordinate frame.

The system measures of performance are functions of system parameters. As the x's in equation (1) vary over their allowable range, so also do the MOPs generating a *locus* in the MOP space. The transformation from parameter to system locus is illustrated in Figure 5.2. Analagously, a set of values that satisfy mission requirements are mapped to form a mission locus (Figure 5.3).

The seventh step is the key in analyzing effectiveness. In this step the system MOPs and mission Requirements are quantitatively compared through the geometric properties of the intersection of the two loci (step 6). These relations may take on either of two forms:

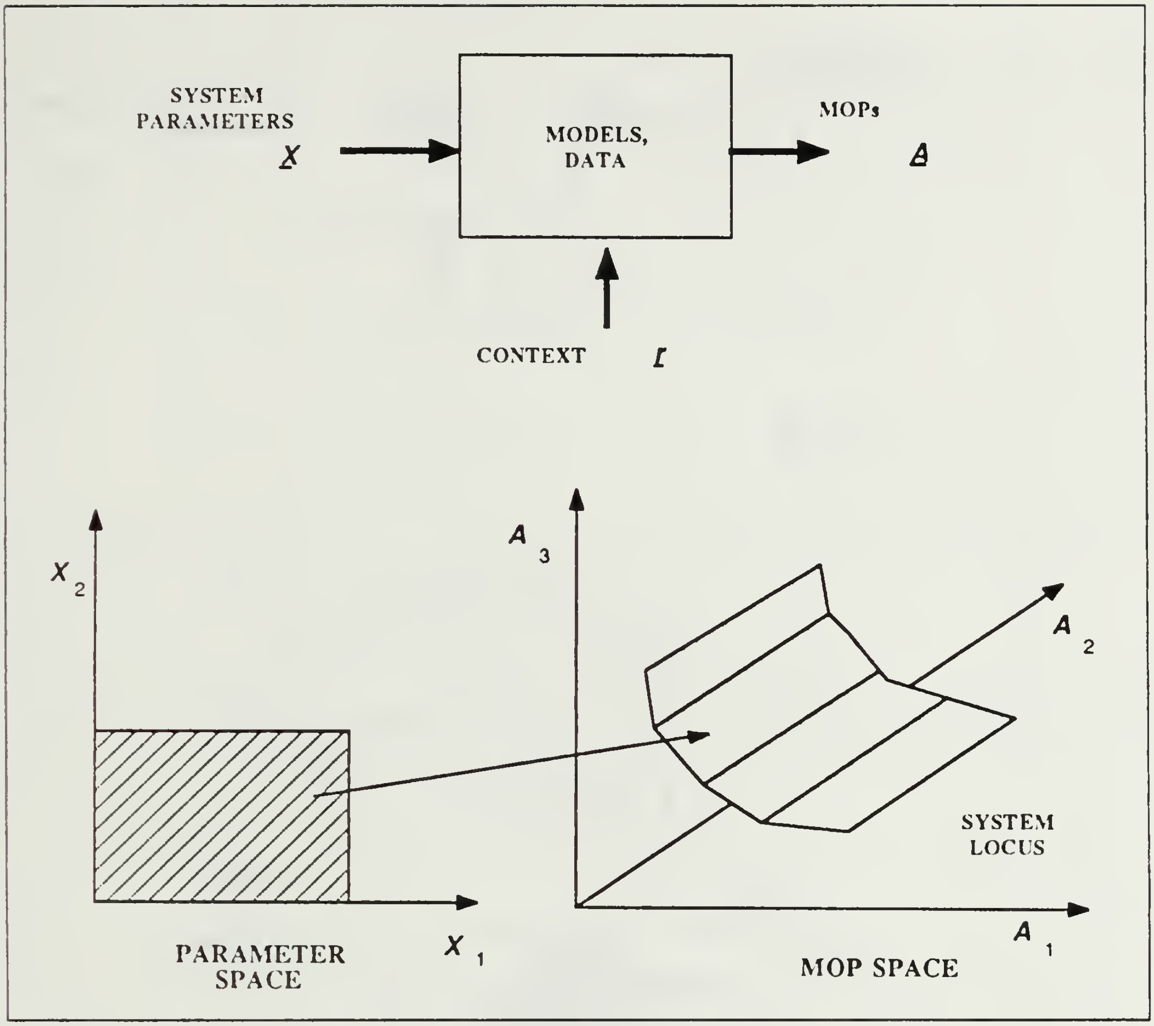

Figure 5.2 System Locus.

(1) The two loci do not have any points in common, i.e., the intersection of L_s and L_m is null:

$$L_s \cap L_m = 0 \qquad \text{(eqn 5.3)}$$

In this case, the system does not satisfy the mission's requirements, and one would define the effectiveness to be zero, regardless of which specific measure is used (Figure 5.4).

(2) The two loci have points in common, but neither locus is included in the other:

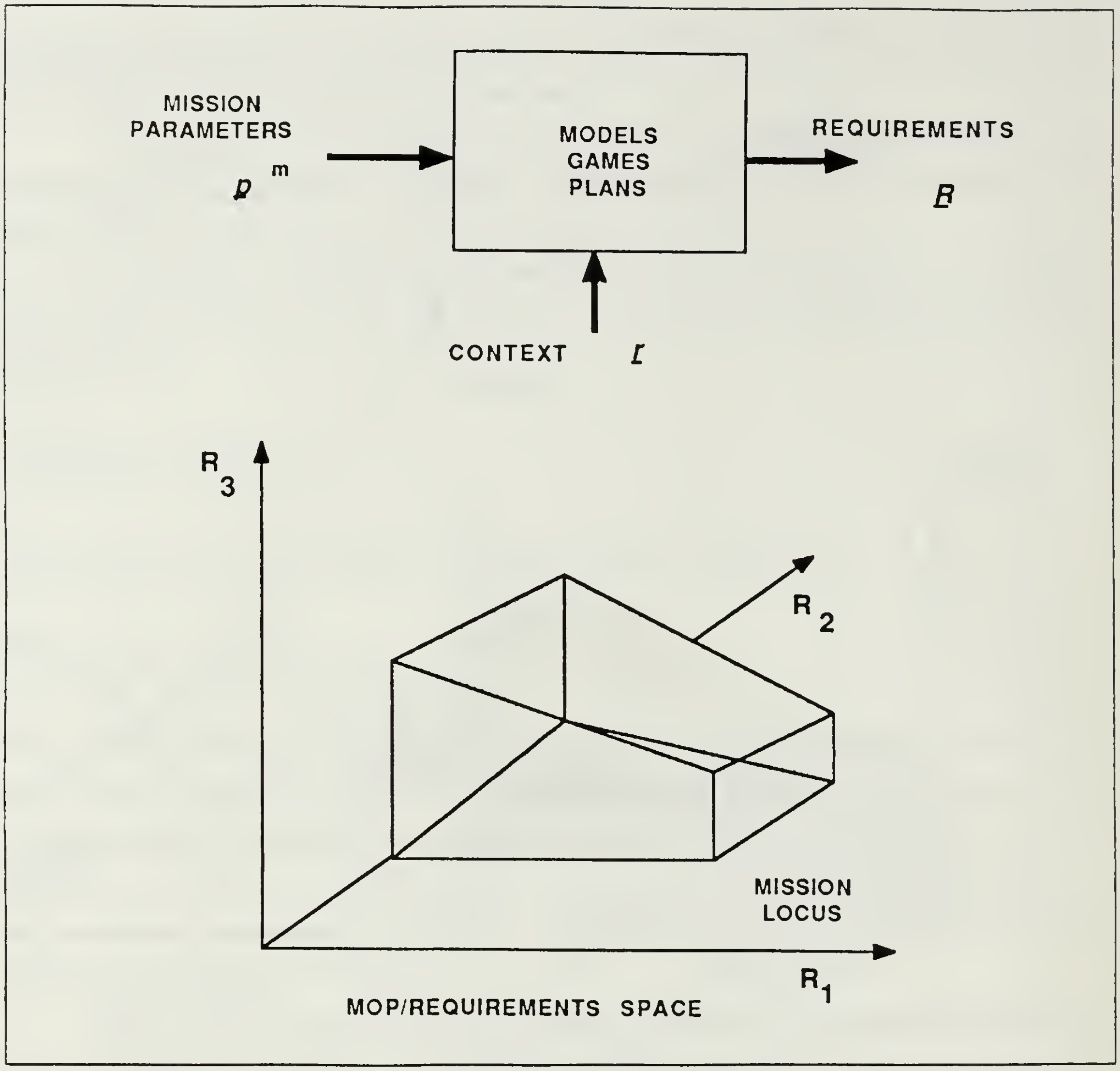

Figure 5.3 Mission Locus.

$$L_s \cap L_m \neq 0 \qquad \text{(eqn 5.4)}$$

with

$$L_s \cap L_m < L_s \text{ and } L_m \qquad \text{(eqn 5.5)}$$

In this case, a subset of the values that the MOPs may take satisfies the mission requirements (Figure 5.5).

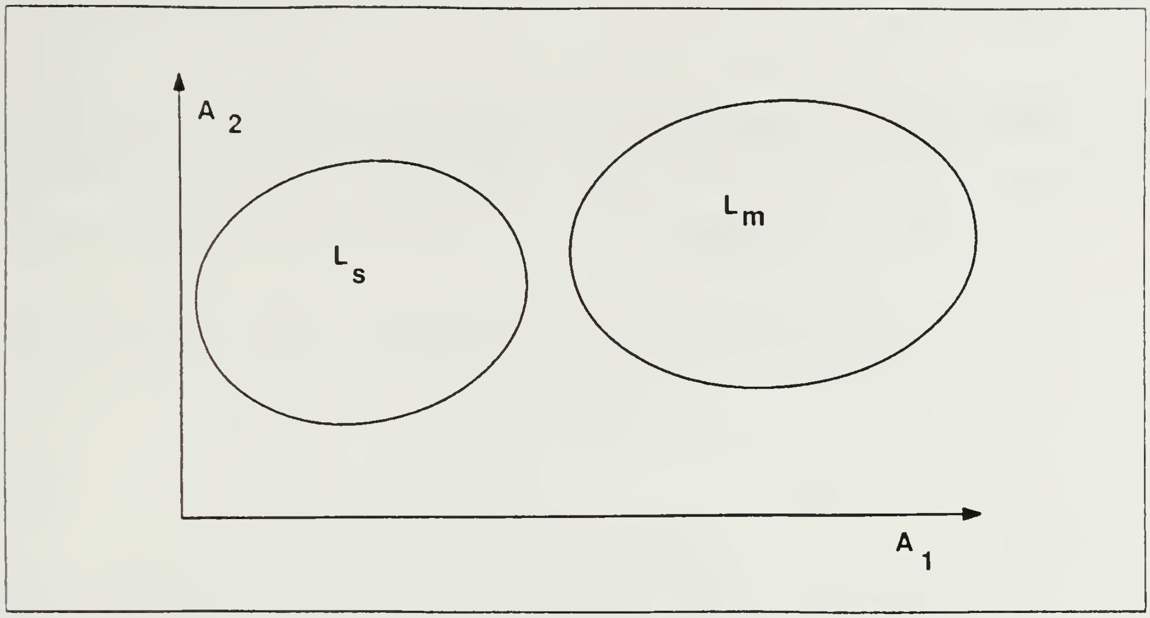

Figure 5.4 Form One.

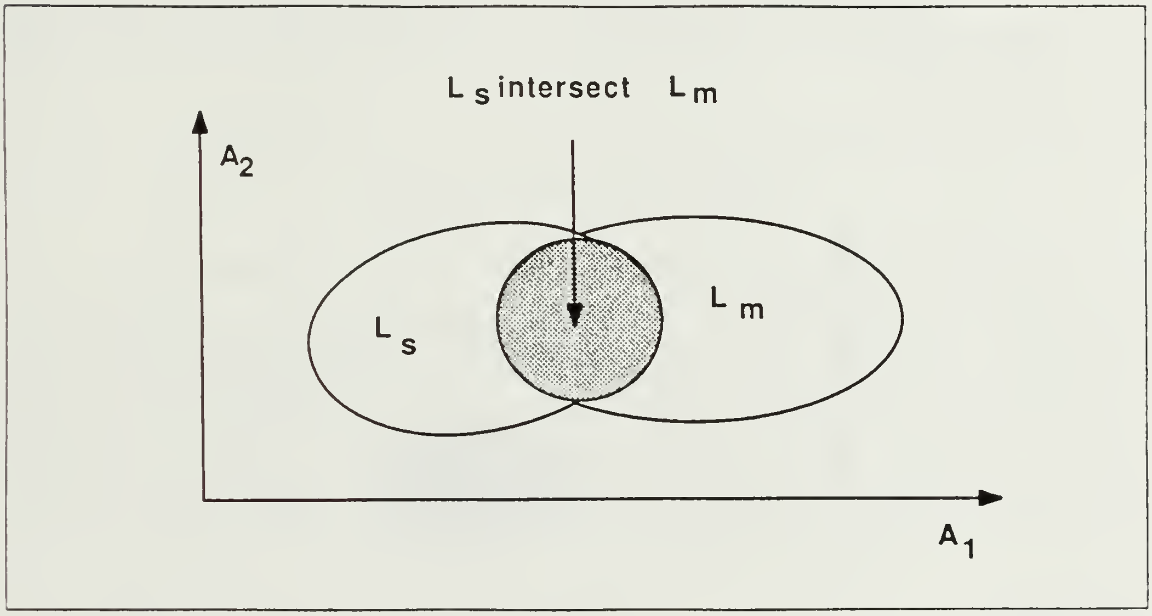

Figure 5.5 Form Two.

Many different measures can be used to describe the extent to which the system meets the requirements. Each of these measures may be considered an MOE. For example, let Ψ be such a measure. Then an effectiveness measure can be defined by

$$E_1 = \Psi(L_s \cap L_m)\ \Psi(L_s) \qquad \text{(eqn 5.6)}$$

which emphasizes how well the system capabilities are used in the mission, while

$$E_2 = \Psi(L_s \cap L_m)\ \Psi(L_m) \qquad \text{(eqn 5.7)}$$

expresses the degree of coverage of the requirements by the system capabilities. Two special cases of the intersection include:

$$L_s \cap L_m = L_m \qquad \text{(eqn 5.8)}$$

In this case, it follows from Equation 5.8 that L_s is larger than L_m and, consequently, the ratio defined by Equation 5.6 will be less than unity. This result can be interpreted in two ways. first, only certain system attribute values meet the requirements of the mission. The second interpretation is that the use of this system for the given mission represents an inefficient use of resources since the system capabilities exceed the mission requirements. Inefficiency, in turn, implies lower effectiveness (Figure 5.6). Alternatively,

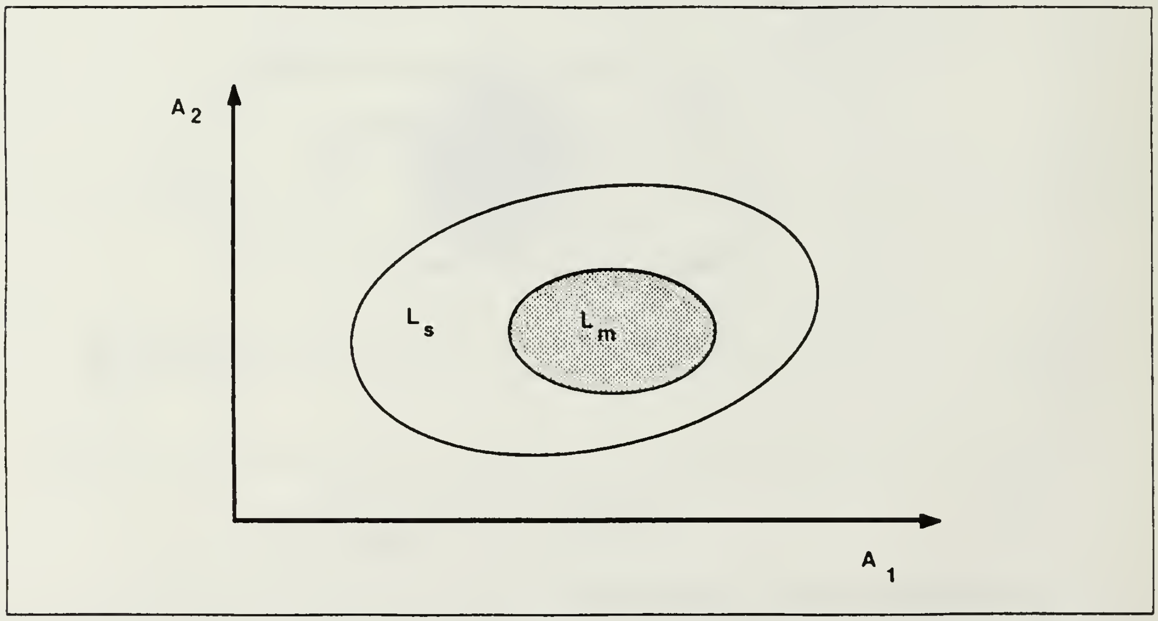

Figure 5.6 Form Two, Case A.

$$L_s \cap L_m = L_s \qquad \text{(eqn 5.9)}$$

The system locus is entirely contained in the mission locus which might imply that the system completely satisfies the mission requirements. However, there are ranges of mission requirements not satisfied by the system (Figure 5.7).

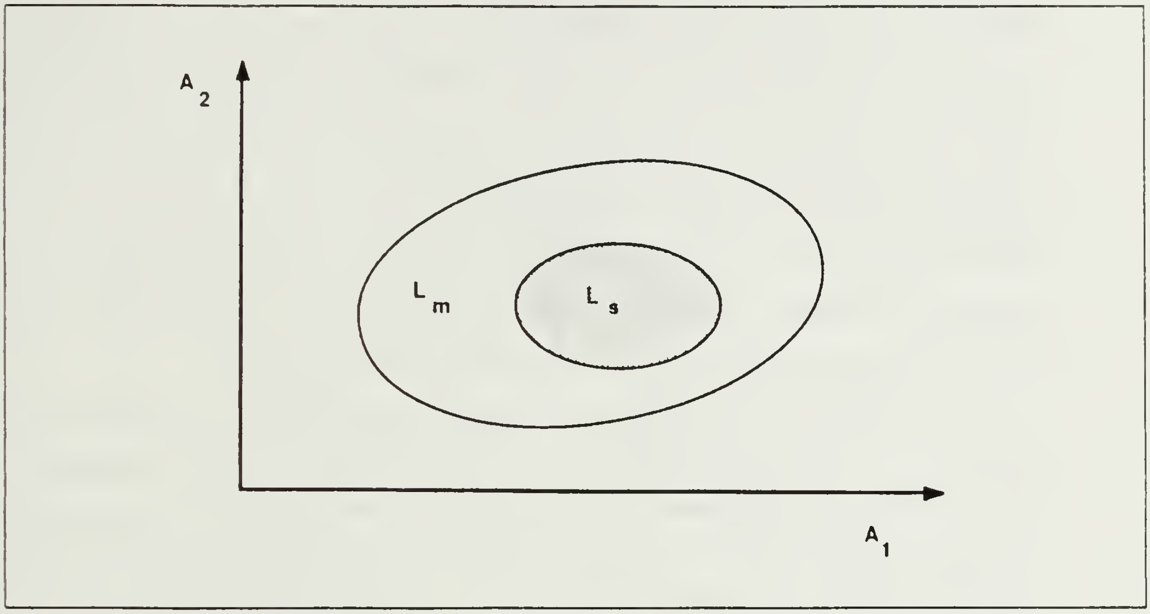

Figure 5.7 Form Two, Case B.

The measures of effectiveness given by Equation 5.6 or Equation 5.7 are partial measures. Let these partial measures be denoted by $\{E_r\}$. To combine these into a single global measure, utility theory may be used. Therefore, the subjective judgements of the system designers and the users can be incorporated directly into the methodology in two ways: (1) by choosing different partial measures, and (2) by selecting a utility function. The global effectiveness measure is obtained, finally, from

$$E = u(E_1, E_2, \ldots, E_k). \qquad \text{(eqn 5.10)}$$

This is the last step of the SEA methodology and corresponds to the seventh module of the MCES.

D. COMMENTS

A graphic representation of the System Effectiveness Analysis methodology is shown in Figure 5.8. This presentation implies, as has been stated, that Mission and system parameters are derived independently. This aspect of SEA and MCES procedures is in keeping with the Office of Management and Budget (OMB) requirement to express requirements in mission terms [Ref. 5]. This represents a goal to which all acquisition managers should subscribe. Through successive iterations of each process both parameters are adjusted to construct an efficient/effective structure. The mission requirements will normally represent a 'first-cut' or goal for the system. The system attributes describe contractor or other technical capabilities to meet the mission requirements. Examination of the differences allows for redefining goals or 'forcing' technological progress. Broad disparities may also cause project termination before additional resources are spent on an imprudent venture.

This presentation of SEA may suggest the necessity to quantify and describe measures in two or three dimensions. In fact SEA has worked command and control problems in up to seven spaces. In such cases, two and three dimensional decision aids are prepared after careful consideration of the processes involved in working each measure. Limiting or forcing the use of only two or three measures in the evaluation causes a loss of information and may adversely affect the decision process.

Finally, it seems apparent to this author that of all the modules of MCES the quantitative aspects of module seven needs additional effort. Detailed mathematical descriptions, beyond the scope of this thesis, are required to relate, generically, the communications processes inferred in Chapter III (Measures). System Effectiveness Analysis provides the logical framework for expansion in this area.

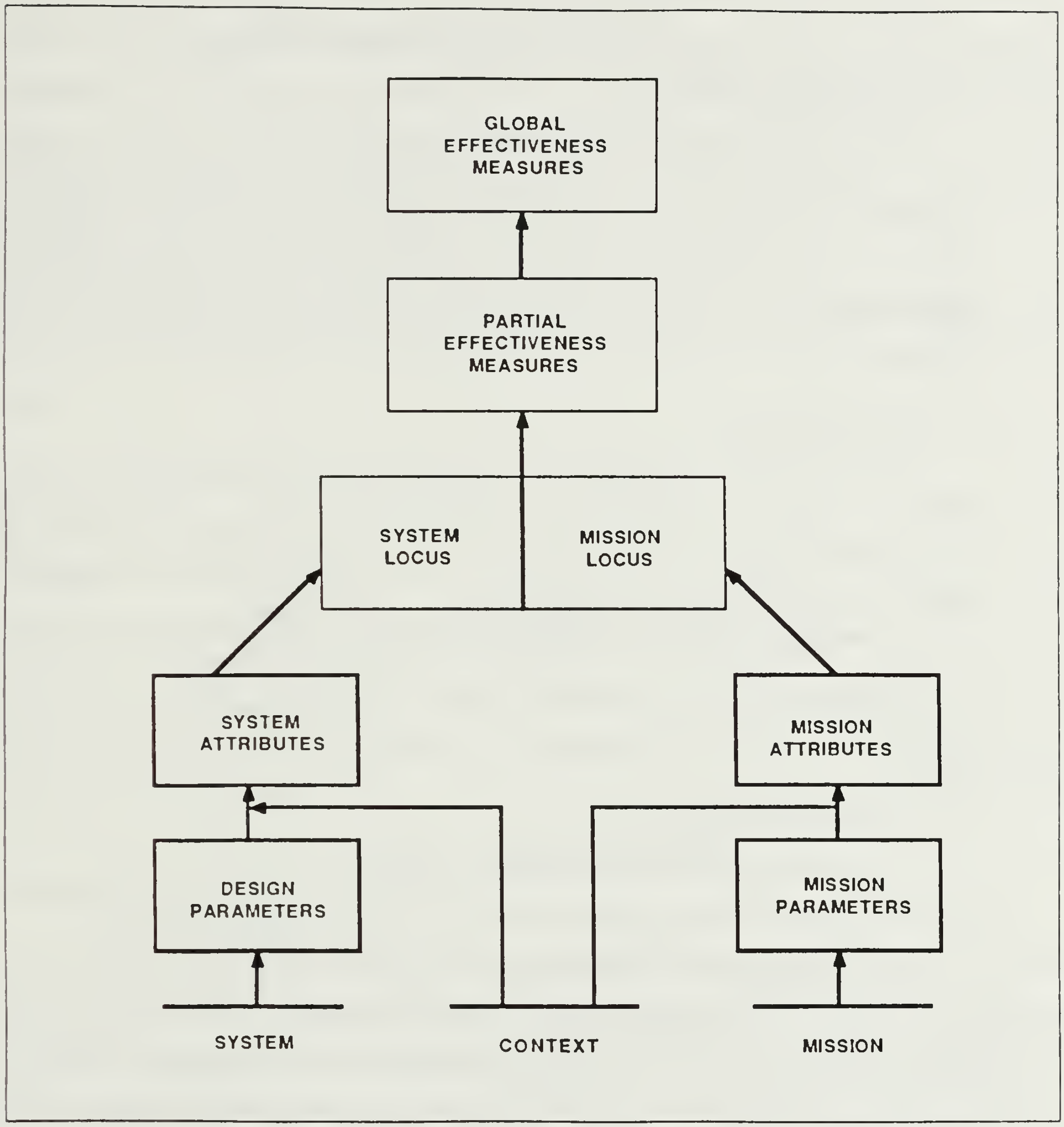

Figure 5.8 The Methodology of System Effectiveness Analysis.

VI. EXAMPLE APPLICATION

A. INTRODUCTION

This chapter serves to demonstrate application of the tools previously described in the acquisition process. The problem addressed is purposely simple allowing, especially in the aggregation module, a graphic portrayal of the analysis process. Analysis of a more complex system would be much more involved requiring a detailed understanding of engineering, mathematics, and decision theory, beyond the scope of this thesis.

B. DESCRIPTION

An architectural evaluation of a large command and control system has been conducted to assess the system effectiveness in light of a recently conducted Mission Area Analysis (MAA). The outcome of the study indicated that the communications element of the architecture was vulnerable to current and projected enemy electronic warfare (EW) platforms. The following sub-sections outline the steps taken to formulate alternatives for the decision making process using the tools discussed in Chapters II-V. Database considerations are separately noted at the end of each sub-section.

1. Problem Formulation

A requirement exists within the C^2 system to transmit data among units. This process is interrupted when an enemy jammer disturbs the link.

Intelligence sources indicate an enemy jamming presence capable of emitting both UHF and SHF broadband noise. The UHF emitter uses a 5db gain crossed dipole antenna and the SHF, a 42db dish antenna. Both transmitters can generate up to 1000 Watts of output power. The jammer operates from an airborne platform; however, because of friendly air suppression, can approach ground based sites no closer than 200 miles. This estimate represents projected capabilities spanning the next ten years.

Database considerations: None specific to this module.

2. C^2 System Bounding

The physical entities of the system are described as Units Alpha and Bravo. These two command and control elements (C^2Es) are first verified to be elements in

the data base and then used to ascertain structure (organization hierarchy and information flow patterns). While Unit Alpha is found to be hierarchically senior to Bravo, the information flow patterns indicate two-way, proportional dialogues; hence, a requirement for full-duplex communication. The bounding process also highlights digital vice analog transmission at a data rate of 1200 bps for the current terminal devices and 2400 bps upgrades during the next decade. Units Alpha and Bravo operate no closer than 200 and no further than 800 miles apart. The physical depiction of the bounding process is shown in Figure 6.1.

Database considerations: If a C^2E is not found in the database, then justification for inclusion is compiled and submitted to the database manager for action.

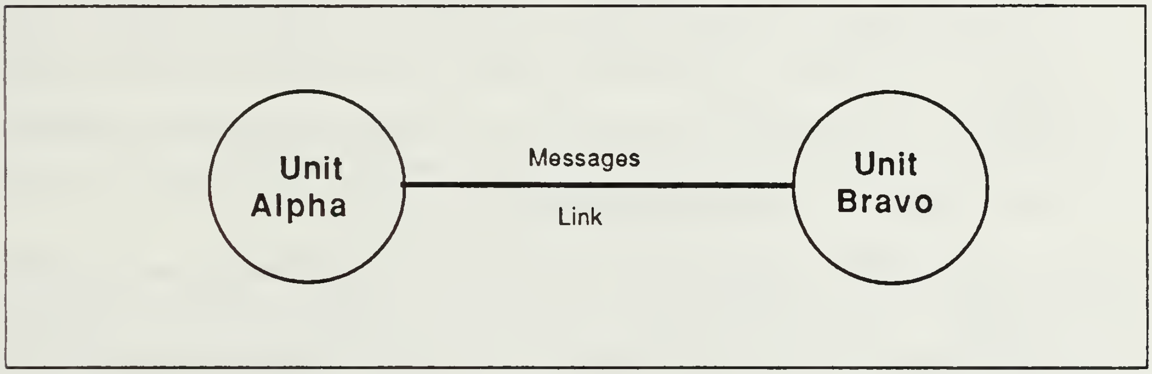

Figure 6.1 Bounded System.

3. C^2 Process Definition

The C^2Es and the most basic link requirements were described in the 'bounding' module. Following the MCES and Marine Corps descriptive processes, outlined in Chapters II and IV, it is now necessary to derive the message standards (or C^2 process function) prior to system integration. This section borrows from the architectural process definition conducted (assumed) prior to this communications system study. During the previous evaluation, the environmental 'initiator' of the C^2 process, the internal C^2 mechanisms, and the desired outputs were manipulated and appraised over varying scenarios or contexts. C^2E tasks and information requirements are generated and used to specify the message standard(s). Tasks are decomposed into subtasks. The subtasks specify message elements which are described in the Message Elements Dictionary (MED) as Data Field Identifiers/Data Unit Identifiers

(DFI DUIs). This functional decomposition describes, alphanumerically, the command and control process of interest.

Database considerations: Specific DFI/DUIs are assumed to exist in the database. If the database is missing these identifiers, justification is provided to have them included.

4. **Integration**

The bounded system (C^2Es and links) coupled with required processes (messages) forms Message Exchange Occurrences (MEOs). These MEOs are analyzed and used to depict the overall requirement in the form of a command and control flow diagram (C^2FD)(Figure 6.2). The MEO (or set of MEOs) is then compared with existing standards using the interoperability database. For purposes of this explanation, the C^2Es and message standard elements exist as specified in the MEOs. The link standards, while similar, will vary as a result of friendly and threat technological change. The database (MEOs) will be used, however, for initial system evaluation. This process allows analysis of existing systems prior to specification of new hardware or software requirements, thus verifying that changes are necessary to meet the mission objectives specified in Module 1.

Database considerations: Assuming, as in this case, that the C^2Es and DFI/DUIs exist in the database, and that link standards exist for the system under consideration, once a new communications system is developed, a means must exist for differentiating between the former and current MEOs. As long as the older links are in use, a distinction is necessary for the new parameters.

5. **Measures of Performance**

While all of the generic measures described in Chapter III may be applicable, this analysis will focus on speed, survivability, and flexibility.

Database considerations: The database *may* contain information pertaining to previous evaluations. This information should include any measures used in conducting the study.

6. **Data Generation**

The performance of the communications system must be ascertained using (a) data generation technique(s) (see database considerations). The system itself must meet the following requirements:

- speed: 1200 to 4800 bps
- survivability: 10^{-3} to 10^{-7} BER
- flexibility: ability to operate varying bit rates over the required range

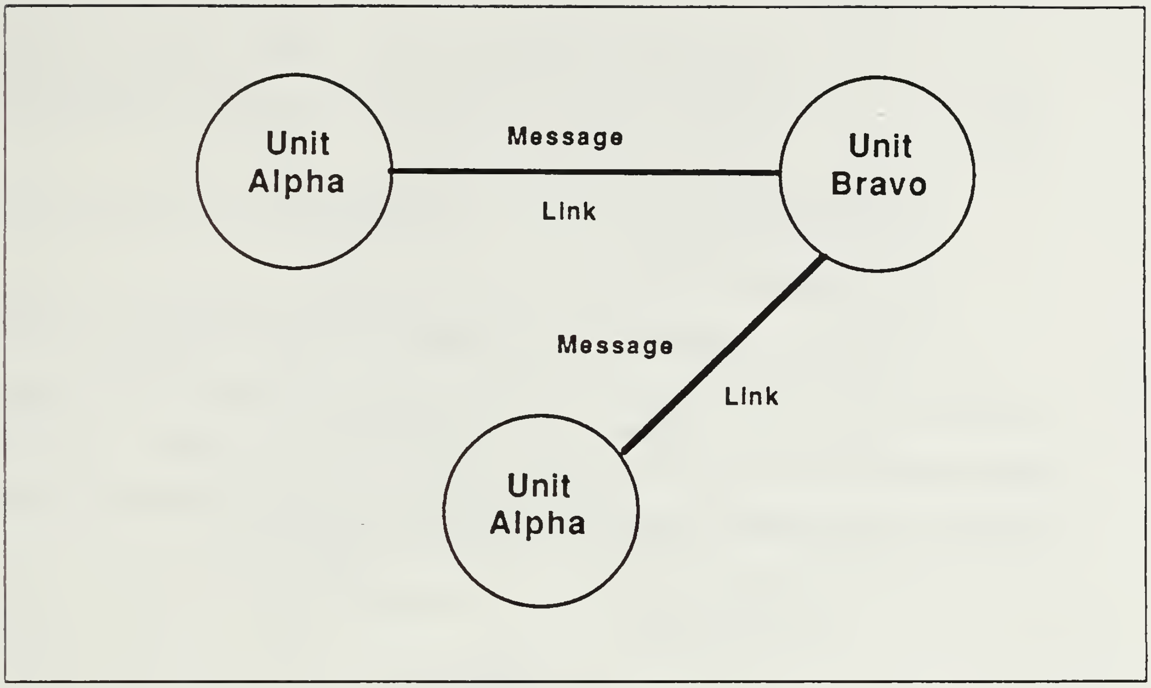

Figure 6.2 Integration Depiction.

The speed requirement meets both current and anticipated (1200-2400bps) terminal capabilities. The additional 2400bps allows engineers flexibility in design, yet caps available speed avoiding spending for unnecessary capacity. The Bit-Error-Rate (BER) specifications should meet current and planned needs and also set an upper limit on expenditures. The flexibility measure is subjective. It is included for the decision maker to choose between identical or nearly identical systems proposals.

Database considerations: This data is based on both subjective judgement and specifications available for the current system (found in the IDB).

7. **Aggregation of Measures**

The final module addresses synthesis of the mission requirements and then compares existing and proposed systems with these baseline (mission) needs. The aggregation process will use the descriptive tools of Systems Effectiveness Analysis (SEA)(Chapter V) to ensure requirements are met.

Database considerations: The final check on whether the system meets mission requirements is conducted by verifying the completion of all MEO tasks and subtasks.

C. ANALYSIS

As stated in the thesis introduction, this section assumes knowledge of communications engineering principles. The following additional assumptions apply to the system analysis:

1) Operating distances and jammer standoff will remain the same over the project life-cycle.
2) The jammer will always be able to work within the footprint of the satellite antenna and outside the range of friendly air-suppression systems.

The system currently in use will help determine a baseline for the analysis. An AN/TSC-1 is used at Unit Alpha and an AN/GRC-1 at Unit Bravo. Tables 9 and 10 outline their respective specifications. The system uses a geostationary full processing satellite as a relay platform described in Figure 6.3 and Table 11.

TABLE 9
TSC-1 SPECIFICATIONS

(Tactical Satellite Communications)

Frequency:	SHF (7.5-8.5 Ghz)
Antenna:	10 meter parabola Sidelobes, -30 db
Transmitter:	
Power Amplifier:	8000 Watts
Receiver:	
G/T	14 db
Modulation:	
Spread Spectrum	(5 Mhz chip rate)
PSK	
Data Rates	75,150,300,600 1200 or 2400 bps

Figure 6.4 highlights the current performance based on the specifications previously addressed. As evidenced by the performance line, outside the bounds (data generation) of the desired requirements, the existing system does not meet the

TABLE 10

GRC-1 SPECIFICATIONS

(Ground Radio Communications)

Frequency	UHF (225-400 Mhz)
Antenna	Inverted Discone Gain = 9db
Transmitter:	
Power Amplifier	100 Watts
Receiver:	
Noise Figure	6 db
Modulation:	
Frequency hop	Hop Bt = 175 Mhz
PSK	
Data Rates	75,150,300,600, 1200 or 2400 bps

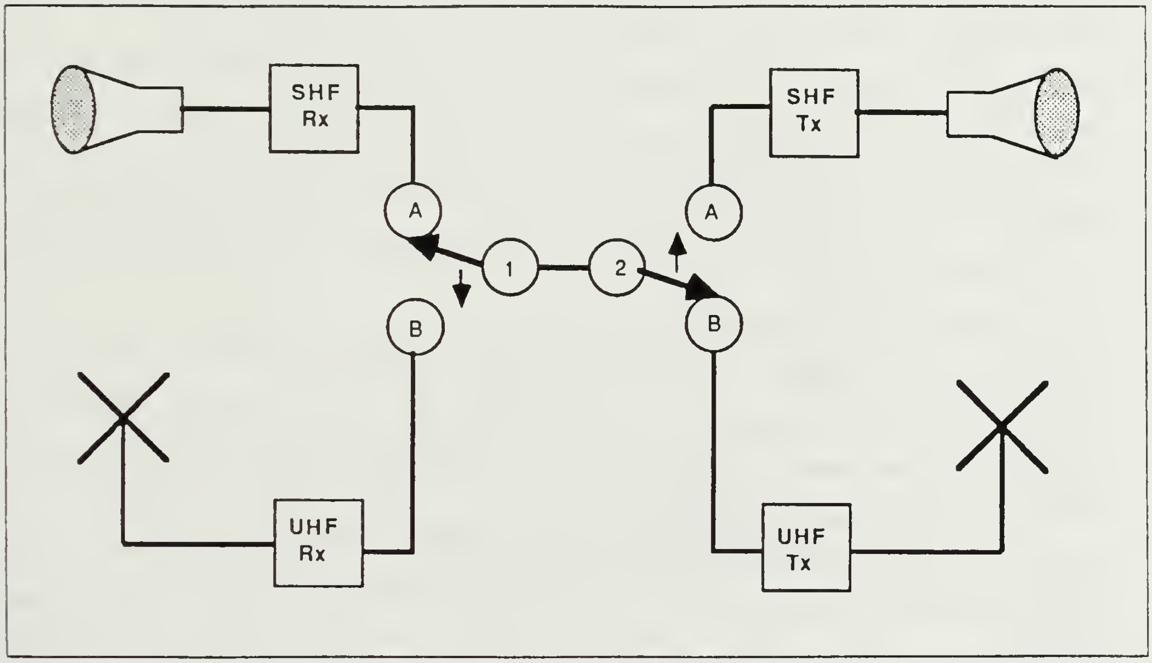

Figure 6.3 Satellite Block Diagram.

TABLE 11

SATELLITE TECHNICAL PARAMETERS

Uplink	SHF	UHF
Antenna:	Horn (Gain = 29 db)	Crossed dipole (Gain = 4 db)
G/T:	0 db	-26 db
Channel Carrier	8 Ghz	Hopped
Receiver Bandwidth	10 Mhz (Spread)	Hopped (225-400 Mhz)
Downlink	**SHF**	**UHF**
Antenna:	Horn (Gain = 29 db)	Helix (Gain = 9 db)
Power:	TWTA (40 Watt)	Solid State (200 Watt)
Channel Carrier	8.3 Ghz	Hopped
Transmit Bandwidth	10 Mhz (Spread)	Hopped (225-400 Mhz)
Modulation	PSK	PSK

standards. It now remains to further refine the mission performance space in order to assure that request for proposal (RFP) specifications give designers an accurate description of requirements and channelize their efforts in keeping with budgetary limits and mission requirements. The mission requirements relate performance as a function of data rate and bit-error-rates. The budget limits are constructed given cost-performance data.

Figure 6.5 illustrates a hypothetical cost-performance curve for this communications system. While any number of curves may be realistic in this application, lacking actual data, this curve represents the author's opinion that as performance improves, cost increases at an increasing rate. Inasmuch as future terminal applications will push the communications system past current technology, research and development costs will increase. By keeping cost/performance in line with budget constraints, an upper limit in the mission space can be generated. Such a limit, when applied to Figure 6.4 may look as projected in Figure 6.6. The line indicates that as performance increases it will cost more for the system. At lower speeds (1200bps) adding funds will produce more significant gains in bit-error-rate; whereas, at higher speeds (4800bps) a similar addition of funds nets less improvement in BER.

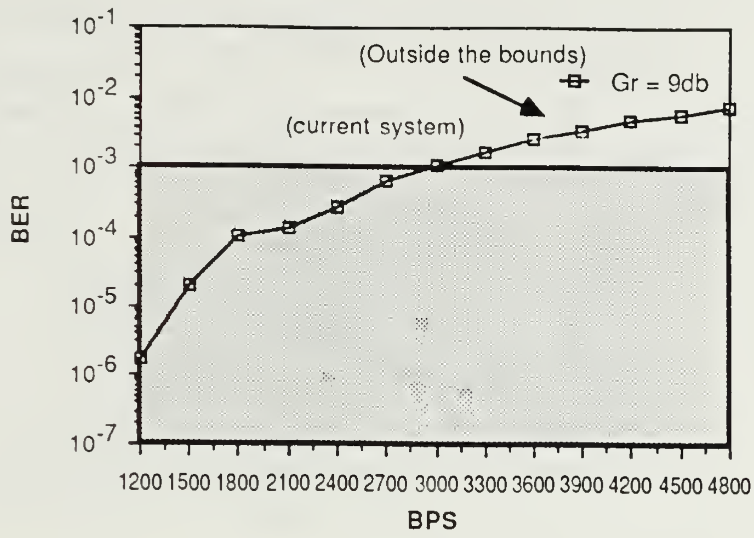

Figure 6.4 System Performance.

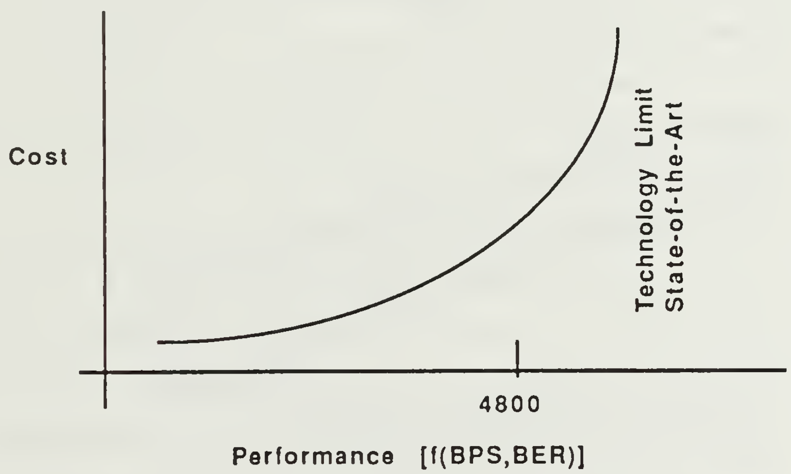

Figure 6.5 Cost-Performance Curve.

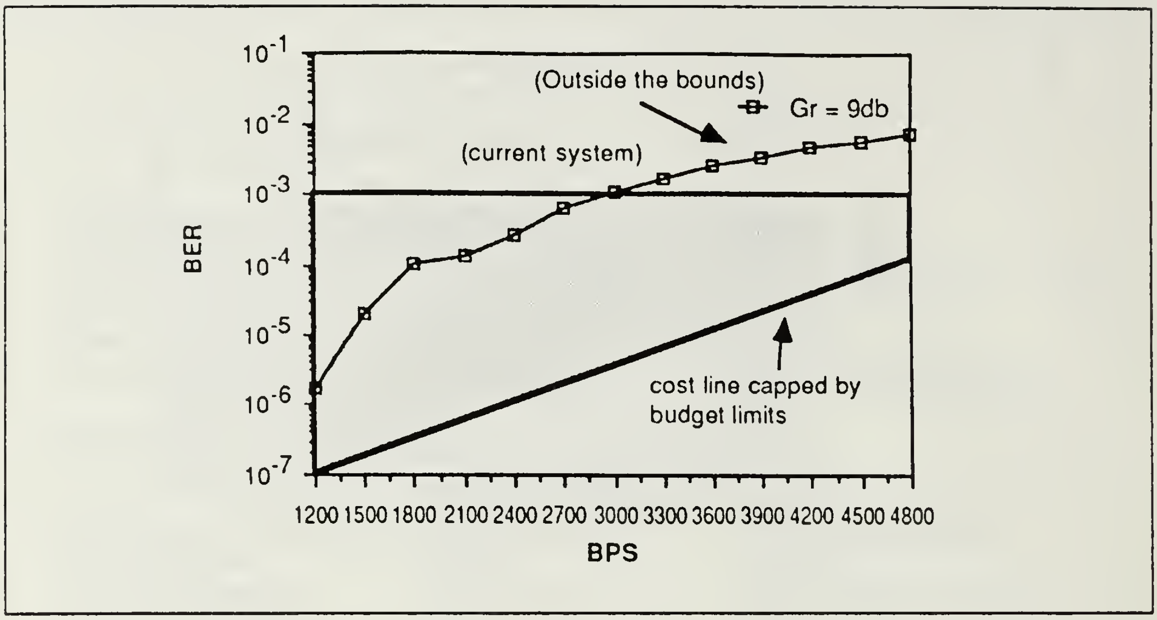

Figure 6.6 System Performance with Cost Line.

Systems planners and engineers have indicated that current terminal equipment requires a 10^{-5} BER @1200bps and no worse than 10^{-3} BER @4800bps to sustain desired thruput in current and future applications. While thruput is used as a measure in both mission and cost line determinations, the mathematical formulation of inputs will vary. Hence, the BER line (mission) will not be parallel to the cost line previously addressed. Both limits assume a linear relationship that may or may not exist. The BER limits line is shown in Figure 6.7. This line indicates the minimum acceptable performance to meet mission requirements.

A realistic estimate of the mission space based on speed and survivability is compiled in Figure 6.8 by combining Figures 6.4 through 6.7. This picture gives the designer a more definitive, measure oriented description of the desired system. It also focuses the analysis and decision process, in that alternative systems outside the shaded area 'C' are either too expensive (area 'B') or unacceptable given the threat and terminal requirements (area 'A'). Figure 6.8 highlights the fact that the original (bordered square) requirements space (10^{-3} to 10^{-7} BER and 1200 to 4800bps) allowed too much leeway in the system design process.

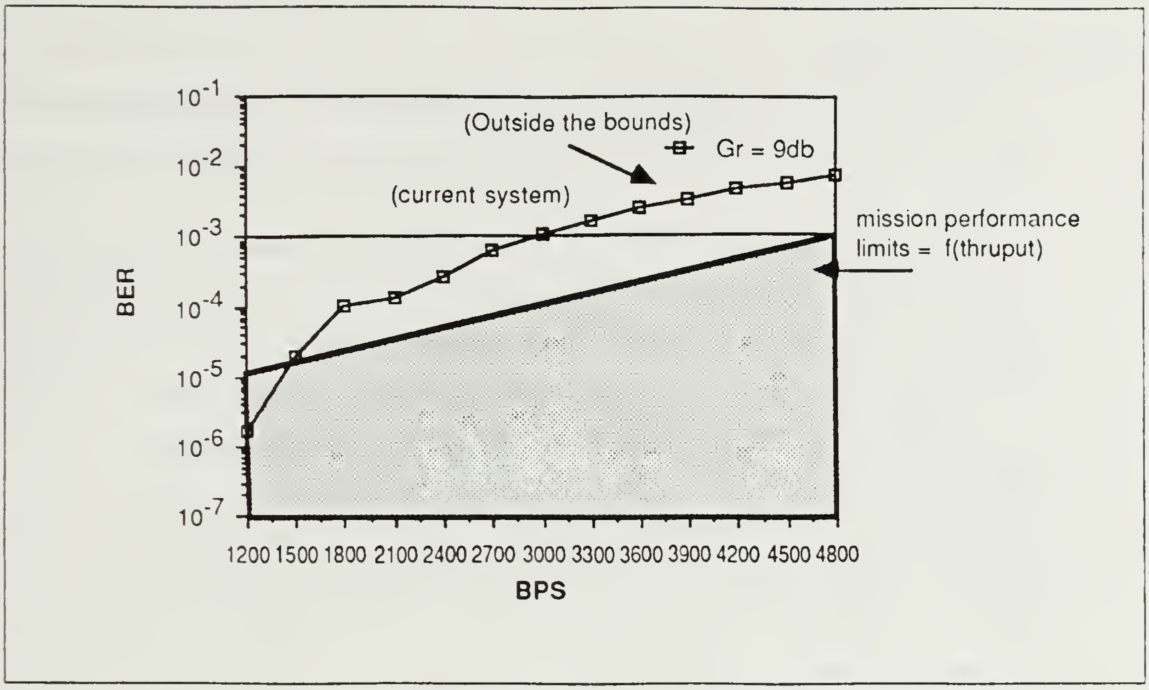

Figure 6.7 System Performance with BER Limits.

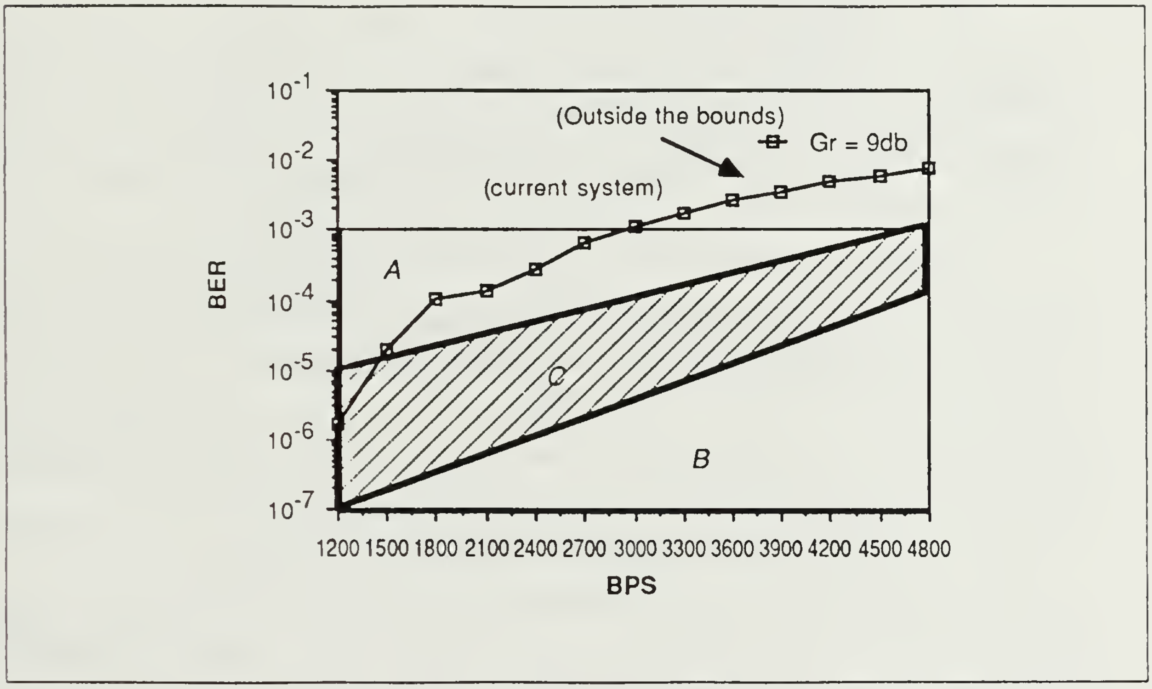

Figure 6.8 Mission Performance Space.

D. SUMMARY

This chapter has demonstrated, through analysis of a simple project, use of the tools previously explained in this thesis. Several comments relative to the analysis are in order.

The communications system of interest was made purposely simple to demonstrate flow between the modules of MCES and to highlight the supplementary tools from which the modules are filled. A detailed explanation of cost-performance analysis is beyond the scope of this thesis, hence the cursory examination in Section C.

Another area intentionally omitted is a detailed examination of the measures chosen for this application. Again, the measures chosen are used to demonstrate the methodology, not to define hard-and-fast guidelines for analysis of like systems. As previously explained, many measures could have been included in the analysis. This would have required a detailed study of not only the source of data, but also the mathematical manipulations necessary to present the information in understandable form. As mentioned in Chapter V, the modelling of parameters to create or support measures of performance or effectiveness is perhaps the hardest concept in this collection of tools to deduce or to comprehend.

Finally, the decision process has been omitted. The intent of this work is to explain and provide an easily understandable framework within which acquisition projects can be evaluated short of an actual decision. The decision process is multi faceted, as highlighted in Chapter II. The information provided in Figure 6.8 will be useful in framing this effort.

The project manager or decision authority has refined the original data generated in Module 6 to the point where a viable mission space has been created. Alternative communications systems that fit or more closely fit the space may provide a logical choice for contract award. As an example, if the receive antenna gain (Gr) were adjusted to 10 or 11db, new system curves, relative to the mission space, can be created (Figure 6.9). Such an adjustment may provide additional direction to engineers or validate the alternative system's claim to requirements satisfaction.

It is not certain from the information provided what percentage of compliance with the mission requirements is met by any of the alternative systems. The intersection of the 'system performance line' with the mission space is in actuality a collection of points, which, mathematically, cannot be assigned a percentage compliance. This highlights a potential problem with presentation of requirements in

either two or three-dimensional space. While the picture gives a more accurate description of desired ranges, it should not, at least in this application, be used to fully evaluate the project. The implication here is that if the system line falls in band "C", then it meets the stated requirements and must be selected. Since none of the systems fall completely within the band, presumably no selection can be made. Had the evaluation been conducted using additional measures, the possibility of answering the mission requirements may have been enhanced insofar as the pictorial presentation is concerned. Ultimately, if the constraints, as functions of other parameters, are allowed to vary, a more dynamic decision process is created. Stated otherwise, by adding more dimensions (measures), the possibility of compliance with requirements or tradeoffs within the mission bounds is improved. The project manager must define the judgement criteria, in percentages or otherwise, as part of the decision process and provide this criteria in the request for proposal (RFP), specifically in the statement of work (SOW).

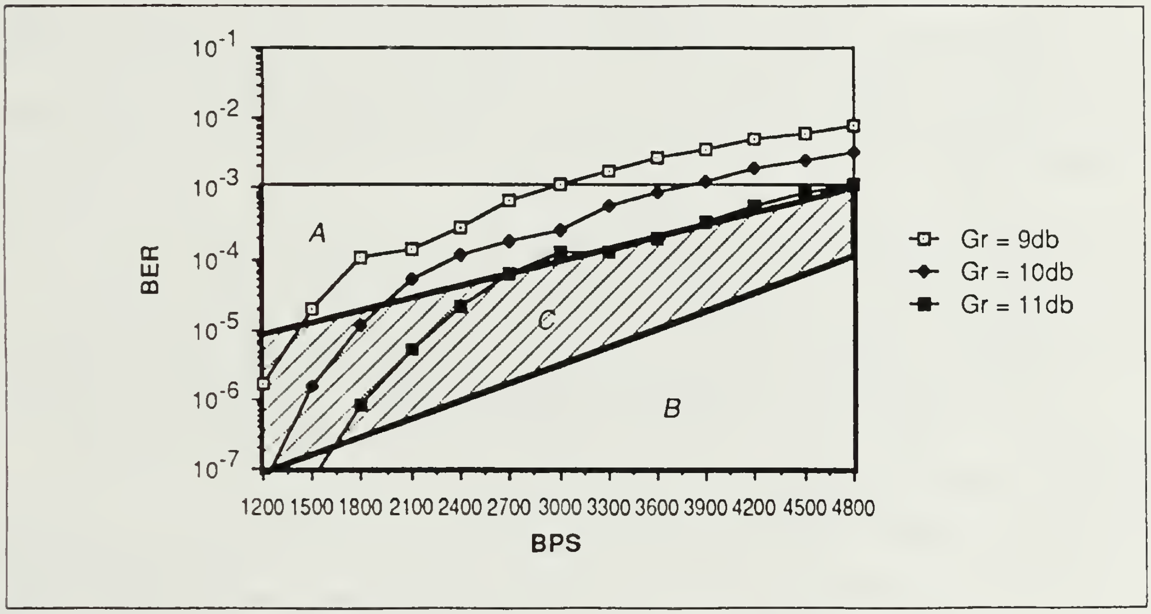

Figure 6.9 Alternative Communication Systems.

VII. CONCLUSIONS/RECOMMENDATIONS

A. SUMMARY

This thesis has described and explained the use of four tools recommended for project managers when procuring communications systems. The Modular Command and Control Evaluation Structure (MCES) provides the framework for this approach. It is used initially at the architectural level to evaluate the command and control system of interest. Depending on the application, this process may start globally at the National Command Authority (NCA) level, working successively through the command hierarchy to a particular C^2 system. At the C^2 system level, communications, weapons systems, intelligence sources, displays, and computer devices are evaluated as to their contribution to the effectiveness of the C^2 system.

Three tools have been discussed as means by which the modules of MCES are implemented. Generic measures of performance/effectiveness for the communications system have been described. Marine Corps Technical Interface Concepts have been used to bound the problem, define the C^2 process required of the bounded structure and then integrate the system elements and functions. The Marine Corps interoperability database (IDB) is proposed as a source for data to quantitatively describe the generic measures specified for the system. The third tool, System Effectiveness Analysis (SEA), serves to assist in the data generation process and to analyze and refine (aggregate) the chosen measures bounded by mission needs and budgetary constraints. All of these means serve as aids in the decision process.

B. CONCLUSIONS

Use of a structured approach in the evaluation and acquisition processes helps ensure that all dimensions of the problem are considered. common terms, definitions, and procedures help managers understand the process they are directing and assists decision makers by presenting facts and alternatives in a common format. The existance of databases of information pertaining to structure, processes and specifications will help managers to evaluate existing systems. The manager can also use this common source of data as a baseline in exploring future applications. Continued application of these tools, relative to the database, will sustain maintenance of the information contained therein, helping to assure accurate future assessments.

C. RECOMMENDATIONS

Work on this thesis has suggested to the author five areas of potential study relative to the processes described.

First, concerning problem formulation, Mission Area Analysis (MAA) is presently used to determine the need for system evaluation. An explanation of the methodology of MAA would enhance the problem formulation module of MCES.

Second, the generic measures presented herein are the author's interpretation of significant performance requirements for a communications system. Review of other documents suggests additional measures are applicable. For example, availability and maintainability may be specific measures, rather than criteria dependent on reliability. An effort needs to be made to refine the measure selection process. As has been suggested in this thesis, the parameters used to discern measures of performance effectiveness may be the same; however, formulation of the specific criterion is different allowing measure independence. The interoperability database suggest one means wherein this issue of independence can be evaluated.

Third, this thesis has suggested use of the interoperability database as a means whereby baseline systems can be defined for the analysis process. Modeling of the system with all of its elements (people, processes, and equipment) has been suggested but not described.

Fourth, it has been submitted that the collection of tools illustrated herein serve as an aid to decision makers; however, little has been written on the subject of the decision process. An understanding of the means and psychology of decision making is critical to presentation of viable alternatives that support mission need.

Finally, a simple example has been used to demonstrate the utility of a collection of tools in standardizing the acquisition and evaluation processes. Successive applications with existing and proposed architectures will ultimately validate the usefulness of this framework.

APPENDIX A
DICTIONARY OF ACRONYMS AND TERMS

BER	Bit-Error-Rate
BPS	Bits-Per-Second
C^2	Command and Control
C^2E	Command and Control Element
C^2FD	Command and Control Flow Diagram
C^3	Command, Control and Communications
C^3I	Command, Control, Communications and Intelligence
C/SCSC	Cost/Schedule Control Systems Criteria
CBR	Chemical, Biological, and Radiological
CDR	Critical Design Review
CI	Configuration Item
COC	Combat Operations Center
COMSEC	Communications Security
D/V	Demonstration/Validation
DFD	Data Flow Diagram
DFI	Data Field Identifiers
DoD	Department of Defense
DOE	Department of Energy
DSAM	Direct Support Artillery Mission
DSARC	Defense System Acquisition Review Council
DTC	Design to Cost
DUI	Data Unit Identifiers
ECCM	Electronic Counter Counter Measures
EMP	Electromagnetic Pulse
EW	Electronic Warfare
FCA	Functional Configuration Audit
FO	Forward Observer
FSCC	Fire Support Coordination Center
FSD	Full Scale Development
GOS	Grade-of-Service
IDB	Interoperability Database

IMP	Interoperability Management Plan
IOC	Initial Operational Capability
IPS	Integrated Program Summary
JCS	Joint Chiefs of Staff
JINTACCS	Joint Interoperability of Tactical Command and Control Systems
JMSNS	Justification for Major Systems New Start
JRMB	Joint Requirements Management Board
JTC^3A	Joint Tactical Command, Control, and Communications Agency
LAAM BN	Light Anti-Air Missile Battalion
LCC	Life Cycle Cost
LPE	Low Probability of Exploitation
LPI	Low Probability of Intercept
MAA	Mission Area Analysis
MAGTF	Marine Air Ground Task Force
MCES	Modular Command and Control Evaluation Structure
MEO	Message Exchange Occurrence
MIT	Massachusetts Institute of Technology
MNS	Mission Need Statement
MOD	Measure of Design
MOE	Measure of Effectiveness
MOFE	Measure of Force Effectiveness
MOP	Measure of Performance
MOPE	Measure of Policy Effectiveness
MORS	Military Operations Research Society
MTACCS	Marine Corps Tactical Command and Control Systems
MTBF	Mean Time Before Failure
MTS	Marine Tactical System
MTTR	Mean Time To Repair
NASA	National Aeronautics and Space Administration
OFPP	Office of Federal Procurement Policy
OJCS	Office of the Joint Chiefs of Staff

OMB	Office of Management and Budget
OPFAC	Operations Facility
P^3I	Pre-planned Product Improvement
PCA	Physical Configuration Audit
PDM	Program Decision Memorandum
PDR	Preliminary Design Review
POM	Program Objective Memorandum
PPBS	Planning Programming and Budgeting System
PRR	Production Readiness Review
RDT&E	Research, Development, Test & Evaluation
RF	Radio Frequency
RFP	Request for Proposal
SARC	System Acquisition Review Council
SCP	System Concept Paper
SDDM	Secretary of Defense Decision Memorandum
SDR	System Design Review
SE	System Engineering; or, Support Equipment
SEA	System Effectiveness Analysis
SECDEF	Secretary of Defense
SHF	Super High Frequency
SNR	Signal-to-Noise Ratio
SOW	Statement of Work
SRR	System Requirements Review
TDS	Tactical Data System
TIC	Technical Interface Concepts
TIDP	Technical Interface Design Plans
TRI-TAC	The Joint Tactical Communications Office that preceded establishment of JTC^3A.
UHF	Ultra High Frequency

APPENDIX B
ACQUISITION POLICIES

1. INTRODUCTION

The process of acquiring new government systems is complex. While no single source describes all of the management principles involved in a product's life cycle, the following excerpt from Reference 16 (pp. 1-1 thru 1-5) provides a good overview of the chronology and requirements for governmental procurement. The processes remain essentially the same; however, several structure changes, made since the reference was published, are worthy of note. The DSARC (Defense System Acquisition Review Council) has been replaced by a Joint Resources Management Board (JRMB); and, the Defense Acquisition Executive (DAE) is now the USD(A), Undersecretary of Defense(Acquisition), a new post created in 1986.

2. APPROACH

a. Government Acquisition Policies

Over the past several decades, as large systems have evolved and matured, the problems encountered in the management of these systems have caused the DoD to develop a systematic engineering management process that directs periodic review and control of the program throughout its acquisition and operational life. In the early 1970s, the Office of Federal Procurement Policy (OFPP) was established to provide policies, methods, and criteria for the acquisition of property and services for all executive agencies. In 1976 the Office of Management and Budget (OMB) Circular A-109 was published. The philosophy behind OMB Circular A-109 is for the Government to become a more reliable customer by standardizing its acquisition policies throughout the Government by avoiding major contract delays and cancellations, and to promote an unbiased concept definition. It requires that the Government operating agency establish and justify a valid requirement for a capability, which must be approved by the executive agency head (Secretary of Defense, NASA Administrator, etc.) before involving industry in the system acquisition process. The approval of this needed capability also establishes the priority and theoretically the availability of resources to fulfill the need.

Approval of, for example, a DoD Justification for Major System New Start (JMSNS) or a NASA Mission Need Statement (MNS) initiates the acquisition cycle. Circular A-109 requires that this need be recertified by the agency head upon approval of a selected design concept for test and demonstration, again before committing the system to production. The acquisition process may be terminated at any of these decision points. The DoD approach to be followed using A-109 includes:

- Prototyping and early demonstration to reduce risk
- Program control and ritualized review by the Defense System Acquisition Review Council (DSARC)
- Placing of emphasis on tradeoffs between cost, performance, schedule, and risk.

In May 1981, then Deputy Secretary of Defense (SECDEF) Frank Carlucci proposed a number of changes which became the DoD Acquisition Improvement Program and included:

- Revising DSARC reviews to decentralize responsibility
- Encouraging capital investment to enhance productivity
- Seeking earlier IOC for less ambitious goals, update later
- Incentivizing reliability and maintainability
- Structuring contracts to consider risks shared by Government and contractor
- Putting more emphasis on credibility rather than lowest bid
- Reducing cost and time to procure small items by raising thresholds for direct Program Office and cost data reporting
- Reducing requirements for socioeconomic program burdens
- Making more realistic cost estimates and higher front-end funding
- Permitting purchases with multiyear contracts
- Promoting the use of Pre-Planned Product Improvement (P^3I).

As a result of his actions and the subsequent review and approval process, eight decisions have been made that directly affect the DSARC process:

- DSARC decision milestones are to be reduced to Requirement Validation (Milestone I) and Program Go-Ahead (Milestone II).
- The criterion for DSARC review is increased to $200 million in Research, Development, Test, and Evaluation (RDT&E) and $1 billion procurement in FY80 dollars.
- The DSARC briefing and data requirements are decreased to increase the efficiency of DSARC and other program reviews.
- The appropriate service Secretary or Chief in included in the DSARC membership.
- The Under Secretary of Defense for Research and Engineering (USDRE) remains the Defense Acquisition Executive (DAE).

- Integration of the DSARC and the Planning Programming, and Budgeting System (PPBS) process is accommodated by requireing that fiscally executable programs be presented for DSARC review.
- The JMSNS is to be submitted with the service Program Objective Memorandum (POM) to initiate a new program. The JMSNS defines the mission need, identifies boundary conditions, and provides an initial acquisition strategy outline.

In March 1982 DoDD 5000.1, *Major Systems Acquisition*, was revised to reflect the following acquisition management principles and objectives:

- Ensure effective design and price competition
- Improve system readiness and sustainability
- Increase the stability in acquisition programs through effective long-range planning, use of evolutionary alternatives instead of solutions at the frontier of technology, realistic budgeting and funding of programs for the total life cycle, and planning to achieve economical production rates
- Delegate authority to the lowest levels of the service that can provide a comprehensive review of the program
- Achieve a cost-effective balance between acquisition costs, ownership costs, and system effectiveness in terms of the missions to be performed.

b. **System Life Cycle**

The life cycle for a typical major DoD system acquisition is depicted in Figure A.1, showing both the previous and current practice. The NASA life cycle combines the elements of the DoD conceptual and validation phases into one phase and envisions no production phase; operational and deployment phases are comparable. Regardless of nomenclature the purpose is the same; from establishing the need to placing the system into operation. System Engineering is an iterative process whereby individual aspects of the program, such as design, costs, or risks, for example, are successively reviewed at the designated milestones and the need recertified before additional resources are authorized by the reviewing authority for the continuation of the program. Any DoD milestone decision will be made by the SECDEF only after a formal review or audit of the contractor effort by Government Program Office personnel. These reviews, which increase in depth of detail as the system life cycle progresses, form the basis for the presentations that Government program managers will use to justify further development of the program. It must be emphasized that for an actual program, the agency head must decide either to continue the present phase, proceed to the next phase, or cancel the program. The SecDef can also direct a DoD Program to omit Demonstration/Validation and proceed with Full Scale Development. A similar cycle is required for "less than major systems," but with Service or Major Command Milestone approval instead of DoD.

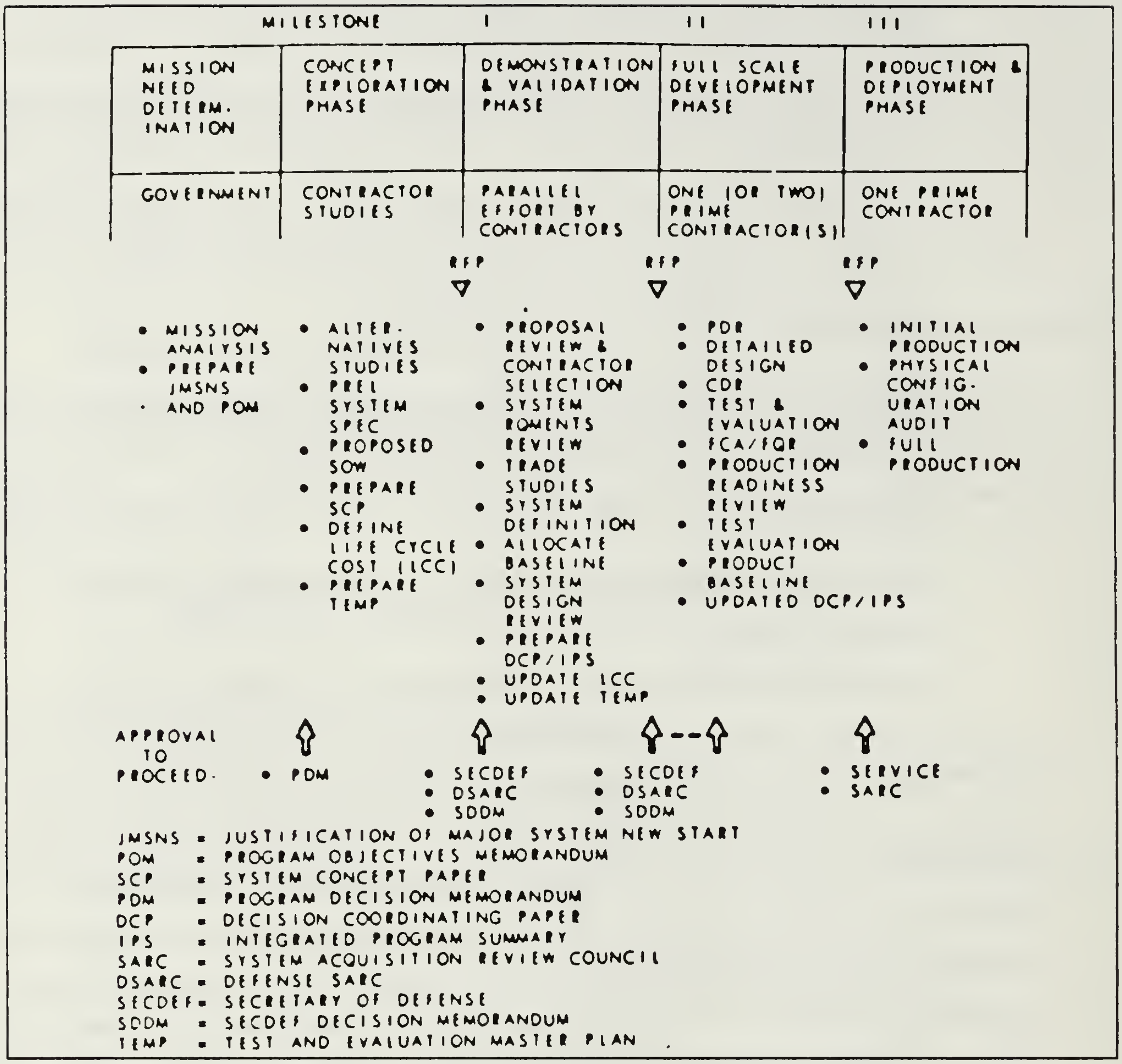

Figure A.1 Major DoD System Life Cycle (Ref. DoDD 5000.1).

1. Concept Exploration (CE) Phase

Concept Exploration (CE) is initiated with the approval of the service POM, which includes the JMSNS by the SECDEF, who signs the Program Decision Memorandum (PDM). It extends to the program decision that authorizes accomplishment of either Demonstration/Validation or Full Scale Development phases. Approval by SECDEF is contingent upon the DoD component having sufficient reserves to complete concept Exploration. This phase defines and selects system concepts for further development. Most activity during this phase is an internal

Government responsibility; however, several parallel short-term contracts are required by OMB circular A-109 to promote the most cost-effective solution. The output from the contractor effort must define performance envelopes, identify risks, present preliminary alternative design concepts, and determine the production feasibility of the design, with schedule estimates and a preliminary Life Cycle Cost (LCC) estimate. These will be used by the Government to establish a functional baseline, usually in the form of a Type A System Specification (Ref. MIL-STD-490). The output should also contain a proposed Request for Proposal (RFP) for the Demonstration/Validation phase. The output from these contractor efforts is reviewed by Government program management for adequacy. A System Requirements Review (SRR) may be accomplished here or very early in the Demonstration/Validation phase. Following this, Government and contractor efforts are combined into a System Concept Paper (SCP) which contains an updated needs statement, a description of alternatives with performance estimates, an acquisition strategy, a program structure management plan, and a risk assessment. The SCP is the basis for review and decision to proceed into further program phases. The SCP is reviewed first by the service component System Acquisition Review Council (SARC) and, if approved, the DSARC. This review constitutes Milestone I.

The DSARC reconfirms the need, determines that risks are adequately considered and that program structure, technical planning, and LCCs have been established. When the SCP meets all objectives,it is forwarded to the SECDEF with recommendations to proceed to the Demonstration/Validation or Full Scale Development phase. Approval by SECDEF is documented in a SECDEF Decision Memorandum (SDDM) and authorizes the service to prepare and release an RFP. The RFP contains the functional baseline, management approach, and the Statement of Work (SOW) that describes the scope of the contractor effort for the approved phase.

2. *Demonstration/Validation (D/V) Phase*

The Demonstration/Validation (D/V) phase is initiated by the release of an RFP by the Government. After proposal evaluation and contract award, the System Engineering (SE) becomes a contractor effort, usually by two or more contractors. The D/V competitive environment may be maintained through Full Scale Development (FSD). The objective in the Validation phase is to determine whether to proceed with FSD. The output of this phase should establish firm and realistic performance specifications (allocated baseline) that meet the operational and support requirements

of the contract SOW. This allocated baseline, which is also described as a design requirements baseline, incorporates technological approaches proposed to satisfy requirements established by the functional baseline. As the System Engineering process progresses from the functional to the allocated baseline, required configuration Items (CIs) are identified. The process includes trade studies to ensure that the system being defined satisfies the functional baseline and the SOW requirements with the best possible balance of LCC and Design to Cost (DTC) requirements, schedule, and operational effectiveness. In addition, continual risk assessment of the elements of the proposed system will be made to identify areas of uncertainty that must be overcome in later program phases. Components whose performance is critical to program success may be prototyped to minimize risk. A System Design Review (SDR) will be held at the end of this phase (or early in the FSD phase) to provide a preliminary allocation or requirements to hardware and software CIs, personnel, and facilities. This system design will normally be supported by a proposal for the FSD phase, including program management plans. A Decision Coordinating Paper (DCP) and Integrated Program Summary (IPS) are prepared by the Government Program Office for review by the SARC(s) and DSARC. If all requirements are satisfied, a Ratified DCP/IPS recommending approval is forwarded to SECDEF. A SECDEF approval authorizes contract awards for the next phase.

3. *Full Scale Development (FSD) Phase*

To initiate the FSD phase, the Government negotiates a contract with one or more contractors. The purpose of the FSD phase is to ensure that detail design is complete, major problems have been resolved, achievement of performance requirements has been demonstrated by testing, and the designed system is producible. The type of contract is dependent on perceived program risks, but usually a development contract is a cost-plus-incentive type to encourage innovation and tradeoffs when technical and engineering problems are uncovered in this phase. Continual risk assessment is characteristic of the FSD phase. A cost-type contract award will require the contractor to operate a management system that satisfies Government Cost/Schedule Control Systems Criteria (C/SCSC)(Ref. MIL-STD-881). The FSD design activity is based on Part I specifications (Type B, Ref. MIL-STD-490) and System Engineering documentation, with changes directed by the approved DCP, as the basis for design.

The Preliminary Design Review (PDR) is held after preliminary design effort, but before the start of detailed design. It provides authentication of the Part I, Type B (MIL-STD-490) development specifications. The Critical Design Review (CDR) is conducted for each CI before release of the design for production. These reviews may culminate in a system CDR which reviews the completeness of preceding CDRs and ensures adequacy of interfaces.

The FSD phase provides verification of performance capability before operational use by testing the system or equipment in its intended environment. The results of this testing and any proposed changes, refurbishments, and corrected deficiencies are evaluated in a series of reviews and audits intended to provide confidence that the system has been developed sufficiently to proceed with production for operational use.

The Functional Configuration Audit (FCA) is conducted on each CI before acceptance of the development effort. The CI must represent the configuration released for production and demonstrate compliance with the Part I development specifications (Type B, MIL-STD-490). The Physical Configuration Audit (PCA) may be accomplished in the FSD phase, but is usually done in the beginning of the Production and Deployment phase on the first deliverable CI that is built on hard tooling. A Production Readiness Review (PRR) is held at the end of the FSD phase to verify that the system is ready to proceed into the next phase.

The output of FSD should result in a tested design that meets contract requirements and documentation necessary to enter the Production and Deployment phase, including Part II detail specifications (Type C, MIL-STD-490), a proposed RFP for the Production and Deployment phase, and an update of the plans proposed in the Validation phase. This data package receives a DCP update, SARC, and DSARC review. When all aspects of FSD have been accomplished, the DCP is forwarded to SECDEF for approval of production.

4. *Production and Deployment Phase*

The primary objective of the Production and Deployment phase is to produce and deliver an effective, supportable system at an optimum cost. In a production run where many items are to be delivered, manufacturing is usually accomplished in two segments. The first segment starts with low rate production of initial product batches or blocks and gradually increases to peak rate production as changes resulting from initial operational use, testing, production tooling, and

manufacturing are incorporated. Typically the first production configuration item from hard tooling is subjected to a PCA. Once it has been established that a production article is built in accordance with the Part II detail specifications, the PCA is complete and an approved production baseline is established for the configuration item audited. Once the PCAs for all the CIs are completed, a system level PCA is accomplished and the product baseline for the system is established.

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c.1 Application and expansion of the Modular Command and Control Evaluation Structure (MCES) as a framework for acquisition management.